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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

CONTRIBUTIONS

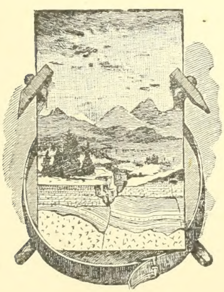
TO

ECONOMIC GEOLOGY

1906

Part I.—METALS AND NONMETALS, EXCEPT FUELS

S. F. EMMONS
E. C. ECKEL
Geologists in Charge



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CONTENTS.

ILLUSTRATIONS.

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1906, PART I.

S. F. Emmons and E. C. Eckel, *Geologists in charge.*

INTRODUCTION.

By C. W. Hayes, *Geologist in charge of geology.*

This bulletin is the fifth of a series, including Bulletins Nos. 213, 225, 260, and 285, Contributions to Economic Geology for 1902, 1903, 1904, and 1905, respectively. These bulletins are prepared primarily with a view to securing prompt publication of the economic results of investigations made by the United States Geological Survey. They are designed to meet the wants of the busy man, and are so condensed that he will be able to obtain results and conclusions with a minimum expenditure of time and energy. They also afford a better idea of the work which the Survey as an organization is carrying on for the direct advancement of mining interests throughout the country than can readily be obtained from the more voluminous final reports.

The first two bulletins of this series included numerous papers relating to the economic geology of Alaska. In view of the rapid increase of economic work both in Alaska and in the States and the organization of a division of Alaskan mineral resources, distinct from the division of geology, it was in 1905 considered advisable to exclude all papers relating to Alaska. These were brought together in a separate volume entitled "Report of Progress of Investigations of Mineral Resources of Alaska in 1904," Bulletin No. 259. A similar segregation of papers relating to Alaska was made last year (Bulletin No. 284) and will be made this year.

During 1906 a further change in the arrangement of the economic bulletin seemed desirable. The former section of iron ores and nonmetallic minerals was divided, M. R. Campbell being placed in charge of a new section devoted to the investigation of fuels, including coal, oil, gas, and asphalts; and E. C. Eckel remaining in charge of investigations of iron ores, structural materials, and miscellaneous nonmetals.

This change in Survey organization has been used as a basis for a separation of the economic bulletin, based on subjects. The present bulletin (No. 315) therefore covers the work of the Survey in 1906 in the metals, structural materials, and other nonmetals except fuels. A separate bulletin (No. 316) will be issued later covering Survey work on coal, lignite, and peat.

In the preparation of the present volume promptness of publication has been made secondary only to the economic utility of the material presented. The papers included are such only as have a direct economic bearing, all questions of purely scientific interest being excluded.

The papers are of two classes: (1) Preliminary discussions of the results of extended economic investigations, which will later be published by the Survey in more detailed form; (2) comparatively detailed descriptions of occurrences of economic interest, noted by geologists of the Survey in the course of their field work, but not of sufficient importance to necessitate a later and more extended description.

The papers have been grouped according to the subjects treated. At the end of each section is given a list of previous publications on that subject by this Survey. These lists will be serviceable to those who wish to ascertain what has been accomplished by the Survey in the investigation of any particular group of mineral products. They are generally confined to Survey publications, though a few titles of important papers published elsewhere by members of the Survey are included.

The results of the Survey work in economic geology have been published in a number of different forms, which are here briefly described:

1. *Papers and reports accompanying the Annual Report of the Director.*—Prior to 1902 many economic reports were published in the royal octavo cloth-bound volumes which accompanied the Annual Report of the Director. This form of publication for scientific papers has been discontinued and a new series, termed Professional Papers, has been substituted.

2. *Bulletins.*—The bulletins of the Survey comprise a series of paper-covered octavo volumes, each containing usually a single report or paper. These bulletins, formerly sold at nominal prices, are now distributed free of charge to those interested in the special subject discussed in any particular bulletin. This form of publication facilitates promptness of issue for economic results, and most economic reports are therefore published as bulletins. Their small size, however, precludes the use of large maps or plates, and reports containing large illustrations are therefore issued in the series of Professional Papers.

3. *Professional Papers.*—This series, paper covered, but quarto in size, is intended to include such papers as contain maps or other illustrations requiring the use of a large page. The publication of the

series was commenced in 1902, and the papers are distributed in the same manner as are the bulletins.

4. *Monographs.*—This series consists of cloth-bound quarto volumes, and is designed to include exhaustive treatises on economic or other geologic subjects. Volumes of this series are sold at cost of publication.

5. *Geologic folios.*—Under the plan adopted for the preparation of a geologic map of the United States the entire area is divided into small quadrangles bounded by certain meridians and parallels, and these quadrangles, which number several thousand, are separately surveyed and mapped. The unit of survey is also the unit of publication, and the maps and descriptions of each quadrangle are issued in the form of a folio. When all the folios are completed, they will constitute a Geologic Atlas of the United States.

A folio is designated by the name of the principal town or of a prominent natural feature within the quadrangle. It contains topographic, geologic, economic, and structural maps of the quadrangle, and in some cases other illustrations, together with a general description.

Under the law copies of each folio are sent to certain public libraries and educational institutions. The remainder are sold at 25 cents each, except such as contain an unusual amount of matter, which are priced accordingly.

Circulars containing lists of these folios, showing the locations of the quadrangle areas they describe, their prices, etc., are issued from time to time, and may be obtained on application to the Director of the United States Geological Survey. The following list shows the folios issued to date and the economic products discussed in the text of each, the products of greatest importance being printed in italic.

List of geologic folios, showing mineral resources described.

No.	Name of folio.	State.	Area in sq. m.	Author.	Mineral products described as occurring in area of folio.
1	Livingston	Mont	3,354	Iddings, J. P.; Weed, W. H.	Gold, copper, clays, limestone, *coal*.
2	Ringgold	Ga.-Tenn.	980	Hayes, C. W	*Coal*, *iron*, manganese, lime, clays, stone, road metal.
3	Placerville	Cal	932	Lindgren, W.; Turner, H. W.	*Gold*, copper, quicksilver, chromite, stone.
4	Kingston	Tenn	969	Hayes, C. W	*Coal*, *iron*, lime, stone, road metal, clay.
5	Sacramento	Cal	932	Lindgren, W	*Gold*, copper, chromite, iron, coal, stone, lime, clay.
6	Chattanooga	Tenn	975	Hayes, C. W	*Coal*, *iron*, lime, stone, road metal, clay.
7	Pikes Peak	Colo	932	Cross, W	*Gold*.
8	Sewanee	Tenn	975	Hayes, C. W	*Coal*, *iron*, lime, stone, road metal, clay.
9	Anthracite-Crested Butte.	Colo	465	Emmons, S. F.; Cross, W.; Eldridge, G. H.	*Coal*, *silver*, gold, stone, lime, clay.
10	Harpers Ferry	Va.-W. Va.-Md.	925	Keith, A	*Iron*, *ocher*, copper, stone, road metal, lime, cement, rock.
11	Jackson	Cal	938	Turner, H. W	*Gold*, *copper*, chromite, iron, manganese, ocher, coal, stone, lime, clay.

List of geologic folios, showing mineral resources described—Continued.

No.	Name of folio.	State.	Area in sq. m.	Author.	Mineral products described as occurring in area of folio.
12	Estillville	Va.-Ky.-Tenn.	957	Campbell, M. R	*Coal,* iron, marble, limestone.
13	Fredericksburg	Md.-Va	938	Darton, N. H	*Greensand marl,* stone, fuller's earth, clays, sand, gravel, *underground water.*
14	Staunton	Va.-W. Va	938	do	Iron, marble, lime, clay, coal.
15	Lassen Peak	Cal	3,634	Diller, J. S	Gold, infusorial earth, lime, stone, coal.
16	Knoxville	Tenn.-N. C	969	Keith, A	*Marble,* slate, stone, gold, lime, cement, clay, water power.
17	Marysville	Cal	925	Lindgren, W.; Turner, H. W.	*Gold,* coal, gas, clay, lime, stone, water.
18	Smartsville	do	925	do	*Gold,* copper, quicksilver, iron, lime, brick clay, stone.
19	Stevenson	Ga. - Ala. Tenn.	980	Hayes, C. W	*Coal, iron* lime, stone, road metal, clay.
20	Cleveland	Tenn	975	do	*Iron,* lead, lime, stone, clay.
21	Pikeville	do	969	do	*Coal,* iron, stone, clay.
22	McMinnville	do	969	do	*Coal,* iron, stone, clay.
23	Nomini	Md.-Va	938	Darton, N. H	*Greensand marl,* fuller's earth, clay, stone, sand, gravel, *underground water.*
24	Three Forks	Mont	3,354	Peale, A. C	*Gold,* silver, copper, iron, coal, lime, clay, pumice, *mineral water.*
25	Loudon	Tenn	969	Keith, A	*Coal,* marble, lime, stone, clay, iron, slate.
26	Pocahontas	Va.-W. Va	950	Campbell, M. R	*Coal,* lime, stone, clay, marble.
27	Morristown	Tenn	963	Keith, A	*Marble, stone,* lead, zinc, lime, cement, clay, water.
28	Piedmont	Md.-W. Va	925	Darton, N. H.; Taff, J. A.	*Coal,* iron, lime, stone, road metal, clay.
29	Nevada City special.	Cal	35	Lindgren, W	*Gold.*
30	Yellowstone National Park.	Wyo	3,412	Hague, A.; Weed, W. H.; Iddings, J. P.	National Park; no mining permitted.
31	Pyramid Peak	Cal	932	Lindgren, W	*Gold.*
32	Franklin	Va.-W. Va	932	Darton, N. H	*Iron,* coal, manganese, lime, stone, road metal, clay.
33	Briceville	Tenn	963	Keith, A	*Coal, iron,* lead, marble, lime, stone, clay.
34	Buckhannon	W. Va	932	Taff, J. A.; Brooks, A. H.	*Coal,* lime, stone, clay.
35	Gadsden	Ala	986	Hayes, C. W	*Coal, iron,* lime, stone.
36	Pueblo	Colo	938	Gilbert, G. K	*Stone, gypsum,* clay, iron, *underground water.*
37	Downieville	Cal	919	Turner, H. W	*Gold,* iron, chromite, lime, marble.
38	Butte special	Mont	23	Weed, W. H.; Emmons, S. F.; Tower, G. W.	*Copper, silver,* gold.
39	Truckee	Cal	925	Lindgren, W	*Gold,* silver, coal, stone, mineral water.
40	Wartburg	Tenn	963	Keith, A	*Coal, oil,* iron, lime, clay.
41	Sonora	Cal	944	Turner, H. W.; Ransome, F. L.	*Gold,* quicksilver, copper, chromite, lime, stone.
42	Nueces	Tex	1,035	Hill, R. T.; Vaughan, T. W.	Stone, gravel, *underground water.*
43	Bidwell Bar	Cal	919	Turner, H. W	*Gold,* manganese, iron, chromite, stone.
44	Tazewell	Va.-W. Va	950	Campbell, M. R	*Coal,* iron, barite.
45	Boise	Idaho	864	Lindgren, W	*Gold,* silver, coal, diatomaceous earth, stone, clay, underground water.
46	Richmond	Ky	944	Campbell, M. R	Coal, fluorite, phosphate, clay, stone, road metal.
47	London	do	950	do	*Coal,* stone.
48	Tenmile district special.	Colo	62	Emmons, S. F	*Silver.*
49	Roseburg	Oreg	871	Diller, J. S	Gold, copper, quicksilver, coal, clay, stone.
50	Holyoke	Mass.-Conn	885	Emerson, B. K	Granite, emery, chromite, quartz, road material, sandstone, clay.

List of geologic folios, showing mineral resources described—Continued.

No.	Name of folio.	State.	Area in sq. m.	Author.	Mineral products described as occurring in area of folio.
51	Big Trees	Cal	938	Turner, H. W.; Ransome, F. L.	*Gold*, silver.
52	Absaroka	Wyo	1,706	Hague, A	Silver.
53	Standingstone	Tenn	963	Campbell, M. R	*Coal*, oil, lime, clay.
54	Tacoma	Wash	812	Willis, B.; Smith, G. O.	*Coal*, *stone*, clay.
55	Fort Benton	Mont	3,234	Weed, W. H	Gold, *silver*, lead, iron, gypsum, *coal*, stone, underground water.
56	Little Belt Mountains.	do	3,295	do	*Coal*, *silver*, lead, copper, iron, *sapphires*, mineral water.
57	Telluride	Colo	236	Cross, W.; Purington, C. W.	*Gold*, *silver*.
58	Elmoro	do	950	Hills, R. C	*Coal*, stone, *underground water*.
59	Bristol	Va.-Tenn	957	Campbell, M. R	*Coal*, iron, zinc, barite, marble, clay.
60	La Plata	Colo	237	Cross, W.; Spencer, A. C.; Purington, C. W.	*Gold*, *silver*, coal.
61	Monterey	Va.-W. Va	938	Darton, N. H	Iron, stone, clay, road metal.
62	Menominee special	Mich	125	Van Hise, C. R.; Bayley, W. S.	*Iro*.
63	Mother Lode district.	Cal	428	Ransome, F. L	*Gold*, silver, manganese, quicksilver, stone.
64	Uvalde	Tex	1,040	Vaughan, T. W	*Asphalt*, gold, silver, iron, coal, underground water.
65	Tintic special	Utah	229	Tower, G. W.; Smith, G. O.; Emmons, S. F.	*Gold*, *silver*, *lead*, *copper*.
66	Colfax	Cal	925	Lindgren, W	*Gold*, stone, clay, water.
67	Danville	Ill.-Ind	228	Campbell, M. R.; Leverett, F.	*Coal*, clay, gravel, underground water.
68	Walsenburg	Colo	944	Hills, R. C	*Coal*, stone, clay, *underground water*.
69	Huntington	W. Va.-Ohio	938	Campbell, M. R	*Coal*.
70	Washington	D. C.-Va.-Md.	465	Darton, N. H.; Keith, A.	Gold, iron, clay, stone, road materials, greensand marls, *underground water*.
71	Spanish Peaks	Colo	950	Hills, R. C	*Coal*, stone, gold, silver, *underground water*.
72	Charleston	W. Va	938	Campbell, M. R	*Coal*, *salt*, *oil*, *gas*, iron.
73	Coos Bay	Oreg	871	Diller, J. S	*Coal*, gold, stone.
74	Coalgate	Ind. T	980	Taff, J. A	*Coal*, stone, clay.
75	Maynardville	Tenn	963	Keith, A	*Marble*, coal, stone, lead, zinc, lime, road materials, clay.
76	Austin	Tex	1,030	Hill, R. T.; Vaughan, T. W.	Oil, stone, lime, clay, cement rock, underground water.
77	Raleigh	W. Va	944	Campbell, M. R	*Coal*
78	Rome	Ga.-Ala	986	Hayes, C. W	*Bauxite*, *iron*, *slate*, lime.
79	Atoka	Ind. T	986	Taff, J. A	*Coal*, stone, clay.
80	Norfolk	Va.-N. C	1,913	Darton, N. H	Sand, clay, *underground water*.
81	Chicago	Ill.-Ind	892	Alden, W. C	*Stone*, clay, molding sand, water.
82	Masontown-Uniontown.	Pa	458	Campbell, M. R	*Coal*, *oil*, *clay*, stone, glass sand, iron.
83	New York City	N. Y.-N. J	906	Merrill, F. J. H.; Hollick, A.; Darton, N. H.; Willis, B., Salisbury, R. D.; Dodge, R. E.; Pressey, H. A.	*Marble*, granite, *road material*, clay, iron, water.
84	Ditney	Ind	938	Fuller, M. L.; Ashley, G. H.	*Coal*, gas, clay, stone, iron.
85	Oelrichs	S. Dak.-Nebr.	871	Darton, N. H	Stone, gypsum, lime, volcanic ash, *underground water*.
86	Ellensburg	Wash	820	Smith, G. O	Building stone, road metal, *underground water*.
87	Camp Clarke	Nebr	892	Darton, N. H	Volcanic ash.
88	Scotts Bluff	do	892	do	Do.
89	Port Orford	Oreg	878	Diller, J. S	*Coal*, gold, platinum.
90	Cranberry	Tenn	963	Keith, A	Mica, gold, brick clay, *iron ore*.
91	Hartville	Wyo	885	Smith, W. S. T	*Iron ore*, copper, lime, building stone, gypsum, fire clay.

List of geologic folios, showing mineral resources described—Continued.

No.	Name of folio.	State.	Area in sq. m.	Author.	Mineral products described as occurring in area of folio.
92	Gaines	Pa.-N. Y	223	Fuller, M. L.; Alden, W. C.	*Oil*, coal.
93	Elkland-Tioga	Pa	445	....do	Flagstone, lime, gravels.
94	Brownsville - Connellsville.	....do	457	Campbell, M. R	*Coal, natural gas*.
95	Columbia	Tenn	969	Hayes, C. W.; Ulrich, E. O.	*Phosphate*, iron.
96	Olivet	S. Dak		Todd, J. E	Granite, lime, quartzite, underground water.
97	Parker	....do	871	....do	Quartzite, chalk, cement rock, underground water.
98	Tishomingo	Ind. T.	986	Taff, J. A	Granite, lime, building stone clay.
99	Mitchell	S. Dak	863	Todd, J. E	*Underground water*, sandstone, chalkstone.
100	Alexandria	....do	863	Todd, J. E.; Hall, C. M	*Underground water*, quartzite, sandstone, chalkstone.
101	San Luis	Cal	975	Fairbanks, H. W	*Bituminous rock*, building stone, road metal, chrome iron, hematite, manganese, pumice, infusorial earth.
102	Indiana	Pa	237	Richardson, G. B	*Coal, gas, fire clay*, brick clay, building stone.
103	Nampa	Idaho		Lindgren, W.; Drake, N. F.	Gold, coal, *opals*, building stone.
104	Silver City	....do	871	....do	*Gold, silver*, coal, opals
105	Patoka	Ind.-Ill	938	Fuller, M. L.; Clapp, F. G.	Coal, gas, oil, asphalt, fire clay, brick clay, building stone, gravel.
106	Mount Stuart	Wash.	805	Smith, G. O	*Gold*, copper, silver, nickel, quicksilver, *coal*, stone, road metal.
107	Newcastle	Wyo.-S. Dak.	864	Darton, N. H	*Coal*, petroleum, *gypsum*, bentonite, salt brines, stone, underground water.
108	Edgemont	Nebr.-S. Dak.	871	Darton, N. H.; Smith, W. S. T.	Water, coal, gypsum, stone, grindstones, underground water.
109	Cottonwood Falls	Kans	938	Prosser, C. S.; Beede, J. W.	Building stone, clay, road metal.
110	Latrobe	Pa.	228	Campbell, M. R	*Coal*, natural gas, building stone, *glass sand*, paving blocks, ballast, lime, salt, *fire clay*.
111	Globe	Ariz	249	Ransome, F. L	*Gold, silver, copper*, lead, lime, building stone, *underground water*.
112	Bisbee	....do	170	....do	*Copper*, gold, lead, clay, silica, building stone, *underground water*.
113	Huron	S. Dak	857	Todd, J. E	Building stone, clay, sand, gravel, *underground water*.
114	De Smet	....do	857	Todd, J. E.; Hall, C. M.	Clay, sand, gravel, underground water.
115	Kittanning	Pa	226	Butts, C.; Leverett, F.	*Coal, oil, gas, clay*, lime, iron, building stone, sand.
116	Asheville	N. C.-Tenn	969	Keith, A	*Talc*, soapstone, *barite*, corundum, garnet, magnetite, iron, marble.
117	Casselton-Fargo	N. Dak.-Minn.	1,640	Hall, C. M.; Willard, D. E.	*Underground water*.
118	Greeneville	Tenn.-N. C	963	Keith, A	*Marble*, building stone, road metal, iron, lime, brick clay.
119	Fayetteville	Mo.-Ark	963	Adams, G. I.; Ulrich, E. O.	Clay, building stone, lime, coal.
120	Silverton	Colo	236	Cross, W.; Howe, E.; Ransome, F. L.	*Gold, silver, copper, lead*, zinc, iron, lime, building stone.
121	Waynesburg	Pa	229	Stone, R. W	*Coal, gas, oil*, building stone, lime, clay, iron, underground water.
122	Tahlequah	Ind. T.-Ark	969	Taff, J. A	Building stone, lime, clay.
123	Elders Ridge	Pa	227	Stone, R. W	*Coal, gas*, oil, building stone, lime, fire clay, stoneware clay.
124	Mount Mitchell	N. C	969	Keith, A	Soapstone, *talc*, mica, precious stones, corundum, graphite, iron, chromite, *building stone*, lime, brick clay.

List of geologic folios, showing mineral resources described—Continued.

No.	Name of folio.	State.	Area in sq. m.	Author.	Mineral products described as occurring in area of folio.
125	Rural Valley	Pa	226	Butts, C	*Coal*, oil, *gas*, fire clay, iron ore, lime, building stone.
126	Bradshaw Mountains.	Ariz	986	Jaggar, T. A., jr.; Palache, C.	*Gold*, *silver*, copper, iron, building stone, onyx marble
127	Sundance	Wyo.–S. Dak.	857	Darton, N. H	Gold, *tin*, silver, lead, *coal*, gypsum, bentonite, *underground water*.
128	Aladdin	Wyo.–S.Dak.–Mont.	894	Darton, N.H.; O'Harra, C. C.	*Underground water*, coal, gypsum, lime.
129	Clifton	Ariz	250	Lindgren, W	*Copper*, iron, lead, gold, kaolin.
130	Rico	Colo	236	Cross, W.; Spencer, A. C.; Ransome, F. L.	*Gold silver*, zinc, lead, building stone, lime.
131	Needle Mountains	do	236	Cross, W.; Howe, E.; Irving, J. D.; Emmons, W. H.	Gold, silver.
132	Muscogee	Ind. T	969	Taff, J. A	Oil, *coal*.
133	Ebensburg	Pa	228	Butts, C	*Coal*, clay, shale, building stone, underground water.
134	Beaver	do	227	Woolsey, L. H	*Clay*, coal, *oil*, gas, building stone.
135	Nepesta	Colo	938	Fisher, C. A	Cement, iron ore, oil, gas, gravel.
136	St. Marys	Md.–Va	938	Shattuck, G. B.; Miller, B. L.	*Clay*, gravel, *underground water*.
137	Dover	Del.–Md.–N.J.	925	Miller, B. L	*Clay*, marl, gravel, *underground water*.
138	Redding	Cal	906	Diller, J. S	*Copper*, gold, silver, iron, clay, lime, stone.
139	Snoqualmie	Wash	812	Smith, G. O.; Calkins, F. C.	*Coal*, iron, gold, quicksilver copper.
140	Milwaukee	Wis	219	Chamberlin, T. C.; Alden, W. C.	*Stone*, lime, *cement*, clay, gravel, underground water.
141	Bald Mountain-Dayton.	Wyo	1,699	Darton, N. H.; Salisbury, R. D.	*Coal*, gold, copper, gypsum, stone, phosphate, *underground water*.
142	Cloud Peak-Fort McKinney.	do	1,713	do	*Coal*, gold, copper, gypsum, stone, phosphate, asphalt, *underground water*.
143	Nantahala	N. C.–Tenn	975	Keith, A	*Marble*, *talc*, kaolin, soapstone, mica, corundum, iron, gold.

6. *Mineral Resources.*—From 1883 to 1894, inclusive, an octavo cloth-bound volume bearing the above title was issued annually, except that the reports for the years 1883–84 and 1889–90 were included by pairs in single volumes. The first of this series was Mineral Resources of the United States, 1882; the last, Mineral Resources of the United States, 1893. In 1894 this form of publication was discontinued, in accordance with an act of Congress, and the statistical material was included in certain parts of the sixteenth, seventeenth, eighteenth, nineteenth, twentieth, and twenty-first annual reports. The separate publication of the series on mineral resources was resumed, however, in 1901, in accordance with an act of Congress, and six volumes of the new series, Mineral Resources of the United States for 1900, for 1901, for 1902, for 1903, for 1904, and for 1905, have been issued.

This publication contains a systematic statement of the production and value of the mineral products of the United States, a summary of new mineral resources developed, and short papers on economic geology when these are necessary to account for the new developments.

INVESTIGATIONS OF METALLIFEROUS ORES.

By S. F. Emmons, *Geologist in Charge.*

ECONOMIC PUBLICATIONS OF THE YEAR.

During the year the following publications on subjects connected with the investigation of metalliferous ores within the United States proper have been issued by the Survey:

Professional Papers:

No. 54. Geology and gold deposits of Cripple Creek district, Colorado, by Waldemar Lindgren and F. L. Ransome.

No. 55. Ore deposits of Silver Peak quadrangle, Nevada, by J. E. Spurr.

No. 57. Geology of the Marysville mining district, Montana, by Joseph Barrell.

Bulletins:

No. 293. Reconnaissance of gold and tin deposits of the southern Appalachians, by L. C. Graton, with notes on the Dahlonega mines by Waldemar Lindgren.

No. 294. Zinc and lead deposits of the upper Mississippi Valley, by H. F. Bain.

No. 303. Preliminary report on Goldfield, Bullfrog, and other mining districts of southern Nevada, by F. L. Ransome, G. H. Garrey, and W. H. Emmons.

No. 308. Geological reconnaissance in southwestern Nevada and eastern California, by S. H. Ball.

No. 312. Interaction between minerals and water solutions, with special reference to geologic phenomena, by E. C. Sullivan.

Bulletin No. 312, though not directly the result of geological field work, has an important bearing thereon, in that it is a chemical investigation of some of the problems that come up most frequently in the study of the origin of ore deposits.

REPORTS FOR WHICH FIELD WORK HAS BEEN COMPLETED, BUT WHICH HAVE NOT YET BEEN ISSUED.

Economic geology of the Georgetown quadrangle (together with the Empire district), Colorado, by J. E. Spurr and G. H. Garrey, with a chapter on geology by S. H. Ball.

Copper deposits of the Butte district, Montana, by W. H. Weed.

Economic geology of the Park City mining district, Utah, by J. M. Boutwell and Lester H. Woolsey.

Ore deposits of the Cœur d'Alene district, Idaho, by F. L. Ransome and F. C. Calkins.

Resurvey of the Leadville mining district, Colorado, by S. F. Emmons and J. D. Irving.

The Neocene auriferous gravels of the Sierra Nevada, by Waldemar Lindgren.

Geology and ore deposits of the Franklin Furnace, New Jersey, quadrangle, by A. C. Spencer.

Unexpected and unavoidable delays in the preparation of these reports have been caused by the resignation or illness of the authors. Messrs. Spurr, Garrey, and Weed have resigned their positions on the Survey to accept more remunerative positions with private corporations, and Messrs. Ransome, Boutwell, and Emmons have been incapacitated for work for several months by illness. These causes have also very seriously curtailed the field work during the last season.

FIELD WORK.

GENERAL DISCUSSION.

An important part of the economic investigation of metalliferous ores during the year has been the personal supervision and direction of that part of the work of the division of mineral resources that has to do with metals other than iron. As has already been outlined in previous bulletins, this work has been put under the personal direction of Waldemar Lindgren, who, in training various assistants to carry out its details, has found it necessary to spend the greater part of the field season in collecting and properly differentiating the statistics of gold and silver. Similar supervision and summing up of the statistics of copper has been placed in charge of L. C. Graton and those of lead and zinc in charge of J. M. Boutwell. This work comprises more than a mere compilation of figures furnished by others to show production. It involves the tracing of the metals back to their various sources and the verification, by comparison and analysis, of the necessarily varying results obtained by different lines of investigation. More than that, its object is to gather at the same time such geological data as will enable the geologists in charge of the respective branches of the work to prepare an annual review of the production and prospects of the different metals in their geological as well as their technical and commercial relations, and thus to provide data for an intelligent forecast of the progress of the industries involved and of the direction it is likely to take.

The regular work in the field of metalliferous investigations has been thus curtailed by the time necessarily devoted to the above purposes; also by that lost during the field season through the illness of three important members of the corps, and by the loss, through resignation, of the services of three other members. The increasing exodus of members of the economic force of the Survey in consequence of their employment by large mining organizations at salaries much greater than those they have been receiving from the Government seriously impairs the efficiency of the work of this branch of the Survey. It is only by years of practical experience in the field that the geologist, however excellent his preliminary training, becomes competent to carry on independent work in investigating a

mining district, and the loss of trained men in this work is, for a time, irreparable. Since the force available has been thus greatly reduced, the field work carried on during the last season has been very largely in the nature of reconnaissance work and has been confined to the Rocky Mountain region. It will be described, as heretofore, by States and Territories.

ARIZONA.

In Arizona Mr. Ransome commenced in October a special study of the Tombstone district, a once famous silver district that has been reopened in the last few years after a long period of idleness. By the end of the month he had completed a preliminary reconnaissance of the district and started for Nevada, where there is an overwhelming demand for geological examinations of many new districts that are constantly springing into existence; but while examining a geological section on the walls of the Grand Canyon of Colorado River the drum of his ear was accidentally punctured by a twig. What was first thought to be a trivial injury proved later to be so serious that he was obliged to submit to a surgical operation and spent several months in a hospital, where he still remains, incapacitated for work.

CALIFORNIA.

In California L. C. Graton has been occupied during the summer in a special and detailed study of several important copper districts on both sides of the Sacramento Valley in Shasta County. These occur in the highly metamorphosed rocks that characterize the western slope of the Sierra Nevada and present a highly intricate geological problem. During a rather short field season he has been able to complete the study of only one of these areas—the Bully Hill district—a report on which will be prepared for publication during the present office season. Work on the other districts will be resumed in the coming summer. Owing to the pressure of his other work, Mr. Graton has been unable to prepare an abstract of this report for the present bulletin.

COLORADO.

In the San Juan region, as an adjunct to the work being carried on under Whitman Cross, L. H. Woolsey made a reconnaissance examination of mines in the Lake Fork quadrangle, whose deposits constitute the eastern continuation of those in the Silverton quadrangle, already described.

In Boulder County, near the mining town of Eldora, Waldemar Lindgren made an examination of an interesting group of thin veins

carrying wolfram, or the tungstate of iron, which now constitute one of the most important sources of tungsten in this country.

In the course of an areal survey of the coal lands to be rendered available by the new Moffat railroad, in and about the valleys of the White and Yampa rivers, Hoyt S. Gale has examined some new deposits of the uranium- and vanadium-bearing mineral, carnotite, which occur in the upturned Dakota sandstones east of the coal basins in Rio Blanco County. These deposits are extremely important as a further possible source of the new metal, radium. Brief reports giving the results of the three reconnaissances mentioned above are included in this bulletin.

MONTANA.

An areal geological survey of the Philipsburg quadrangle, which covers 30 minutes of latitude and longitude, has been carried on during the last summer under the direction of F. C. Calkins. W. H. Emmons was detailed to make an economic examination of this area, which contains numerous important ore deposits. During the summer he completed a field study of the two most important deposits of the region—that worked by the Granite-Bimetallic mine, which is a typical vein deposit, producing silver, and that worked by the Cable mine, which is an auriferous contact deposit in limestone surrounded by granite. A preliminary report on these two mines is given in this bulletin.

NEVADA.

Early in the summer the writer visited the new copper district at Ely, Nev., which promises to become one of the greatest producers of copper in that portion of the country. A railroad 140 miles long was building to develop the district, and large concentrating and smelting plants were planned to treat the low-grade disseminated copper ores in porphyry that have been proved to exist there in large quantities. Preliminary geological reports on the district have already been published in a scientific periodical, and the writer's visit was made simply to determine the area that should be included in a topographical map that will serve as a basis for the special geological study of the district. The topographical survey has since been completed, and it is hoped that it will be possible during the coming season, when the mines shall be actually working, to make an exhaustive examination of the geology and ore deposits of the district.

It has been planned that Mr. Ransome should make a final examination of the Goldfield, Bullfrog, Rhyolite, and neighboring districts in southwestern Nevada, in the light of the latest mining developments, before publishing his report on this region. When it was learned that

Mr. Ransome's accident had incapacitated him for further field work this season, W. H. Emmons was sent to the region after he had completed his field work in Montana, and is now studying the geology of the region at and near Rhyolite. As soon as he is able Mr. Ransome will resume his field work in Nevada, and, it is hoped, will complete the report upon this region before the opening of the new field season. Under the circumstances no abstract of this report has been possible.

OREGON.

In connection with areal work in western Oregon, G. F. Kay has made a new examination of the interesting deposits of silicate of nickel near Riddles, an account of which appears in this bulletin. These deposits have heretofore excited considerable interest because of their close mineralogical and geological resemblance to the famous deposits of New Caledonia, which, up to comparatively recent times, have furnished a large proportion of the world's production of nickel.

The deposits are evidently of secondary origin, but have not yet been found in bodies sufficiently large to be of great economic value. There seems to be, however, no good reason why exploration may not develop ore in amounts large enough to constitute a profitable source of the metal, but such discovery is rather the work of the prospector than of the geologist, since in a region so highly altered it is only by actual mine openings that the localities of ore concentration can be detected.

UTAH.

During the last summer the writer was engaged for a few weeks in studying the geological structure of the western Uinta Mountains, especially of the region around Duchesne River, on the southern flanks of the range—an area that once formed part of the Indian reservation but has recently been thrown open to occupation as mineral land. Deposits of iron ore of good quality and size, as well as small amounts of other metals, have long been known to exist in this region, but no deposit of great economic value has yet been found. The range is remarkable for the entire absence of igneous rocks, the only known occurrence of which are late intrusive sheets in the Mesozoic beds along the Provo Valley, at the extreme western end of the range. All the important deposits of metals except the lead and zinc deposits of the Mississippi Valley are found in regions that are traversed by igneous rocks, and for this reason the Uinta Mountains can hardly, on theoretical grounds, be considered a very favorable locality for the occurrence of these or the more valuable metals. The result of the writer's visit was negative, since he found no evidence of any considerable mineralization.

WASHINGTON.

During the last season A. J. Collier has been occupied, by order of the Secretary of the Interior and in association with an officer of the Land Office, in examining placer lands on the Colville Reservation and along the Columbia and Sanpoil rivers, for the purpose of determining whether certain placer locations were taken up in good faith. He has utilized the geological information obtained during this work for an article on the geological relations of the placer mines of that region, which will be found in this bulletin.

WYOMING.

During an examination of the important iron-ore deposits near Hartville, in Wyoming, S. H. Ball has made some studies of the copper deposits that were worked in this region before the iron ore became valuable. These are of rather unusual form, and Mr. Ball's description, which appears in this bulletin, will be interesting to students of copper deposits.

In connection with an examination of the coal basins in the western part of Wyoming, A. R. Schultz has made a study of gold-placer deposits along upper Snake River and some comparative investigations of placers on the same river in the western part of Idaho. These placers are highly interesting because of the extremely minute particles in which the gold is found—so minute that they evidently must have suffered an immense amount of trituration during the very long journey from their original source in the rocks. Mr. Schultz's article gives an account of the various attempts to work these placers and the results of tests of the black sands collected during the work, which show the character of the various heavy minerals associated with the gold.

INVESTIGATIONS OF IRON ORES, STRUCTURAL MATERIALS, ETC.

By Edwin C. Eckel, *Geologist in Charge.*

INTRODUCTION.

During the last year the Survey has carried on extensive investigations in the field included in the work of this section. Some of these investigations are summarized in this bulletin, but a large amount of economic work of this kind has been done in connection with the ordinary areal work of the Survey, and its results appear only in texts accompanying geological folios.

IRON, MANGANESE, AND ALUMINUM ORES.

IRON.

Southern States.—The Survey's work on southern iron ores was carried out in 1906, as in previous years, under the direct charge of the writer. With E. F. Burchard, a detailed study of the Clinton or red ores of the Birmingham district was taken up and practically completed within the field season. The large amount of data generously placed at our disposal by the iron companies of the district will give the final report on this subject peculiar value and will enable us to make a fairly complete report on the iron ores and iron industry of the most important iron district, aside from Pittsburg, in the United States. In the present bulletin Mr. Burchard has discussed, briefly, the more important facts relative to the Birmingham red ores. The present status of Survey work on the iron ores of Alabama may therefore be summarized as follows:

Commercial, geographical, and geological differences permit the separation of the iron ores of Alabama into six groups—

1. The Clinton, red, or fossil ores of the Birmingham district, including ores occurring in the territory tributary to Birmingham from Springville south through Birmingham to the southernmost outcrop of red ore.

2. The red ores of northern Alabama, including ores in territory tributary to Chattanooga, Attalla, and Gadsden.

3. The gray hematites of Talladega and adjoining counties in eastern Alabama.

4. The brown ores of the Russellville district in northwestern Alabama.

5. The brown ores of the Woodstock district, mostly in eastern Tuscaloosa County.

6. The brown ores of eastern Alabama, occurring in a belt extending from the Georgia State line, near Rock Run, southwestward through the Coosa Valley country to near Brierfield.

During the last three years the United States Geological Survey has carried out more or less detailed work in all of these districts. The present bulletin contains reports on the red ores of the Birmingham district, the Russellville brown ores, and the Talladega County gray ores. Preceding bulletins of this series have contained, as noted in the bibliography on pages 213–214, reports on the red ores of northern Alabama and on the Woodstock brown ores. Work on the brown ores of eastern Alabama has been carried on, but the results are not yet ready for publication.

So far as final publications are concerned, a detailed report on the "Iron ores and iron industry of the Birmingham district," by E. C. Eckel and E. F. Burchard, will be submitted for publication as a Survey bulletin in the spring of 1907. The manner in which the other districts of the State will be handled has not yet been decided.

In Tennessee and Georgia work has also been carried on by the Survey on both the red and brown ores, and it is planned to complete certain sections of this work during 1907.

In Virginia work has also been taken up on the iron ores, but for several reasons, notably the lack of good topographic base maps, no attempt has been made to push it to the point of final publication.

Considered from either an industrial or geologic point, the iron ores of Virginia fall into six groups:

1. Magnetites and specular hematites of the Blue Ridge and Piedmont districts.

2. Red hematites (Clinton ores, "fossil ores," "oolitic ores") of the foothills of the Allegheny Mountains.

3. Brown hematites (Oriskany ores) of the Goshen-Longdale-Oriskany district, mostly in Augusta, Bath, Botetourt, Alleghany, and Craig counties.

4. Brown hematites of the New River-Cripple Creek district, mostly in Wythe and Pulaski counties.

5. Brown hematites of the Roanoke, Shenandoah, and Page valleys.

6. Brown hematites ("gossan ores") of Carroll and Floyd counties.

During 1905 and 1906 detailed field work was done on the ores of classes 3 and 4; the ores of class 2 were examined in less detail at several localities in 1905, while on those of classes 1, 5, and 6 no field work was done. It is planned to complete the work during 1907 by examinations of the ore deposits not yet visited.

Pennsylvania-New Jersey.—A. C. Spencer has for some time been engaged in a very detailed study of the iron, zinc, and manganese deposits of the Franklin Furnace district of New Jersey. In connection with this work he examined a number of magnetite deposits elsewhere in New Jersey and in New York, and has formulated theories of occurrence and origin which seem to have an important bearing on the future development of these ores. The exploratory work so far done by mining companies has been of a rather haphazard nature, based on no definite working theory. It is hoped that the publication of Mr. Spencer's report will supply the prospector and miner with data which will serve as a guide both in locating and valuing the deposits.

At the close of work in the New Jersey area Mr. Spencer took up the study of the important and extensive magnetite deposits which occur near the Triassic border in southwestern Pennsylvania. An introductory report on these magnetites of the Cornwall type is included in the present bulletin.

Western States.—Two distinct fields of work have been entered upon by the Survey in its investigation of western iron ores. S. H. Ball spent most of the field season of 1906 in examining and mapping the important Hartville iron-ore district of Wyoming. A brief preliminary report on the results of this work is included in the present bulletin, and a special bulletin on the subject will be published by the Survey during 1907. At the close of this work Mr. Ball made brief examination of the titaniferous iron ores of Iron Mountain, Wyoming, a report on which is presented later in this bulletin.

In Utah C. K. Leith and assistants carried out very detailed mapping of important iron deposits, and the Survey will probably publish the results of this work in a separate bulletin during 1907.

MANGANESE.

As most of the manganese ores of the United States are closely associated, both geographically and geologically, with brown iron ores, work on the two products is best carried on by the same Survey parties. In the course of the work on the southern iron ores outlined on a previous page considerable data have been collected concerning the manganese ores of Virginia, Georgia, and Alabama.

The prosperity of the steel industry has greatly stimulated interest in the subject of manganese ore deposits, and a marked revival of

activity has occurred in the well-known Crimora district of Virginia and elsewhere. These developments should be promptly followed up by the Survey, and it is desirable that a preliminary general report on the manganese ores of the United States be prepared and issued as soon as possible.

ALUMINUM AND BAUXITE.

During 1905 bauxite was discovered in Tennessee, Virginia, and Pennsylvania, far north of the deposits previously known. Developments in the use of low-grade bauxite for the manufacture of refractory brick have also stimulated interest in the industry, so that prospecting for bauxite has been particularly active during the last year. It is noteworthy, however, that though these new discoveries extended the area known to contain bauxite deposits, the general location and character of the deposits fulfill entirely the conditions pointed out by Survey geologists a decade ago. During 1905 the Arkansas deposits were reexamined by Survey parties, and it is probable that the new eastern districts will be surveyed and reported on in the near future.

The recent and proximate expiration of a number of the basic patents on which the aluminum industry is founded has operated to increase greatly the general interest in the supply of ore; and it seems probable that active prospecting and development work will be carried on in all promising districts during 1907.

A reported bauxite field in Arizona was examined during 1906 by C. W. Hayes, whose report is presented in this bulletin.

STRUCTURAL MATERIALS.

Cement.—The geological investigation of cement materials by the Survey during the last year was carried on mostly in connection with the ordinary areal work of the Survey, and its results will be published only in the texts of various geologic folios. An exception to this, however, was the examination of the cement resources of portions of Wyoming by Sydney H. Ball, a report on which is included in the present bulletin. Mr. Burchard has also submitted a brief report on the cement resources near Dubuque, Iowa, for publication in this volume.

Bulletin 243 of this Survey, dealing with the "Cement materials and cement industry of the United States," has been out of print for some time. The demand for it still continues, and it has been decided to rewrite it completely and issue the revised edition in 1907 if possible.

Lime.—In the course of his studies on the areal geology of the Birmingham district of Alabama, Charles Butts collected considerable

data on the limestones of that region. In two brief papers published in the present bulletin the principal facts relative to the use of these limestones as fluxing materials and for lime burning are summarized.

Magnesia and magnesite.—During the last fall Frank L. Hess continued his investigations of the magnesite deposits of California. The results of this work are not in shape for publication at present, but a special bulletin on the subject will probably be issued by the Survey in 1907 or 1908.

Gypsum and plasters.—Various gypsum districts have been visited by Survey geologists during the past year, and a report on one western district is contained in the present bulletin. During the coming year an attempt will be made to prepare a revised edition of Bulletin 223, on the gypsum deposits of the United States.

Clays.—A number of reports on the clay resources of various parts of the United States are included in the present bulletin. Most of the investigations covered by these reports were carried on by geologists engaged in areal work for geologic folios, but the work and the papers by Messrs. John T. Porter and Otto Veatch form exceptions to this rule.

Building stone.—T. Nelson Dale has continued his studies of the granite deposits of New England, and is preparing a detailed report on the subject for publication during the coming year as a bulletin of the Survey. The present bulletin includes a brief summary of this report.

MISCELLANEOUS NONMETALS.

Glass sand.—The glass-making materials of several areas were studied by Survey geologists during 1905, and the economic bulletin (No. 285) for that year contained three detailed reports summarizing the results of their investigation. Mr. Burchard continued this work in 1906 and presents two reports in the present bulletin. In the course of this work he has carried out chemical and physical tests, not only of glass sands now in use, but of sands from undeveloped deposits which seem to be available for use as glass-making material. It is believed that this investigation, which is of a type somewhat different from those usually undertaken by the Survey, will yield results so valuable that its continuance is warranted.

Feldspar and quartz.—Reports on the feldspar and quartz deposits of two areas, by E. S. Bastin, are included in this bulletin. These represent, so far as known, the first serious studies of this interesting group of mineral products and will probably prove serviceable to those who are engaged in prospecting or working similar deposits in other districts.

Mica.—Papers on mica deposits in Wyoming and North Carolina, by Messrs. Ball and Sterrett, respectively, will be found in this bul-

letin. The more detailed of these studies was carried on for the North Carolina Geological Survey and is presented here by permission of the State geologist.

Graphite.—While studying the iron ores of Wyoming, Mr. Ball prepared for this bulletin a brief note on graphite deposits occurring in the same area.

Diatomaceous earth.—Messrs. Arnold and Anderson have prepared for the present bulletin a comparatively detailed report on the extensive deposits of diatomaceous shale which occur in California.

Mineral paints.—During the last year several mineral-paint producing localities have been visited by Survey geologists, and in this bulletin a statement concerning the use for paint of the Clinton or oolitic red hematite ores is presented by Mr. Burchard.

Phosphates and phosphorus.—Several papers included in the present bulletin deal with interesting deposits of phosphates. Mr. Stose describes the manufacture of phosphorus from mineral materials, while Professor Purdue's paper takes up the recently discovered phosphate fields of Arkansas. The paper by Messrs. Weeks and Ferrier describes a new and important phosphate district in the western United States.

Sulphur.—A brief paper on some Utah sulphur deposits, by W. T. Lee, will be found in the present bulletin. So far no detailed study of the sulphur and pyrite deposits of the United States has been taken up by the Survey, though such an investigation and report would be of great industrial interest and value and should receive consideration in the near future.

GOLD AND SILVER.

LAKE FORK EXTENSION OF THE SILVERTON MINING AREA, COLORADO.

By L. H. Woolsey.

INTRODUCTION.

The Silverton mining district, Colorado, has been under development many years and was described by Ransome and others [a] after examination in 1889 and 1900.

What may be considered a geologic extension of this district has been opened near the head of Lake Fork of Gunnison River, at Whitecross post-office, about 14 miles by road northeast of Silverton and nearly the same distance southwest of Lake City. This area was hurriedly covered by a party under Mr. Whitman Cross during a reconnaissance of the San Cristobal quadrangle in the summer of 1906, and the mines, especially those closely surrounding Whitecross, will be discussed in the present paper from field notes taken by the writer at that time.

GENERAL GEOLOGY.

The geology along Lake Fork, as in most of the Silverton area, is that of an intricate igneous complex. Water-laid rocks, save small amounts of fine, stratified tuffs, are the exception. Though many geologic relations were necessarily undetermined during the stay at Whitecross, the broad geologic features of the region may be stated. An indeterminate breccia, consisting largely of monzonitic flow breccias and tuffs and including some fragments of granite, occupies the bottom of Lake Fork for 2 or 3 miles east of Whitecross. This breccia is extensively invaded and covered by a rhyolite bearing prominent quartz phenocrysts, apparently the same rock as that forming large masses on the higher slopes of the valley and especially on the ridges and peaks to the east. To the south this complex lies against a granite backbone, which has, roughly speaking, an east-west extension for several miles along Cottonwood Creek and Lake Fork to the east. Near the mouth of Cottonwood Creek, however, an arm of

[a] Ransome, F. L., Economic geology of the Silverton quadrangle: Bull. U. S. Geol. Survey No. 182, 1903. Cross, W., Howe, E., and Ransome, F. L., Description of Silverton district: Geologic Atlas U. S., folio 120, U. S. Geol. Survey, 1905.

the granite stretches northwestward to Lake Fork at Whitecross and wedges out a short distance beyond the town. The granite is older than the complex, but their present relations are rendered somewhat equivocal through profound faulting and fissuring, which has affected in greater or less degree all the rocks of the area. The fissures follow no single direction, nor do they fall into regular systems, but have a wide range within the northwest and northeast quadrants. Many of them are offshoots of fissure systems lying well within the Silverton area, and in such fissures the ore mined in this locality largely occurs.

MINING.

This region was prospected many years ago and has been the scene of more or less activity ever since; but development is greatly retarded by the lack of transportation facilities. The nearest railroad is at Animas Forks, 5 miles west of Whitecross, but over a divide requiring a 1,500-foot climb. The railroad at Lake City is nearly three times as distant. Nevertheless, from time to time considerable ore has been shipped from the various mines of the region, and active development is progressing as rapidly as the conditions warrant. Many prospects have workings of several hundred feet, and though some were inaccessible at the time of visit such details as were obtainable are given below. The mines are taken up in order from west to east.

The Park View property lies halfway up the southeast face of Edith Mountain, west of Whitecross. Development has been carried on by means of a tunnel over 600 feet long and a 60-foot shaft some distance above the tunnel. The rock at the surface and underground is granite, which is cut by a main southwest fissure. All workings are said to follow this fissure, which is in places several feet wide. The workings were not accessible at the time of visit, but the vein is known to carry chiefly galena, with smaller amounts of gray copper. Quartz is present as the chief gangue mineral and is said to carry some gold.

The Monticello lode is situated at the mouth of Cleveland Gulch, adjacent to Whitecross, and is developed by a shaft 50 feet deep, with a short southward drift at the bottom. Farther up the gulch a new tunnel is also being opened. The surface rock near both workings is granite, and this is the only rock penetrated underground. The shaft and drift were inaccessible, but are said to follow a southwest fissure. The tunnel, however, is on forking lodes, which shoot through the granite in roughly northeast directions. The ore found in the shaft fissure is said to be chalcopyrite and pyrite mixed with calcite and quartz as gangue minerals, and some of this has been shipped in past years. In the tunnel the granite is heavily pyritized near quartz veins, which hold chalcopyrite in large proportions, and at the face ore was observed in three or more veins, covering in all about a foot and a half in width. No postmineral movement was apparent, for

the veins had frozen walls. Sufficient ore had not yet been taken from the tunnel to make a shipment.

The two Cleveland tunnels are also situated at the mouth of Cleveland Gulch. They are short and but a few hundred feet apart. The rock in the vicinity, as well as underground, is massive granite. Mineralization is confined to impregnations of pyrite and veins of quartz, but in places these have suffered brecciation and fissuring since their formation. Development has not progressed sufficiently far to expose ore of any account.

The Illinois Boy is an old prospect on the east side of Cleveland Gulch. It is opened by a 250-foot tunnel in granite. Ore like that of the Monticello is said to have been shipped occasionally, but at the time of visit the mine was idle.

The Bon Homme tunnel is situated southwest of Whitecross, on the south slope of the valley. At present it is closed under pending litigation. It is said, however, to have penetrated nearly 2,000 feet of massive granite, which is also the country rock at the surface. In this distance, as reported, it intercepted one of the fissures outcropping on the summit of the hill to the south and locally called the Fanny vein. Ore consisting chiefly of chalcopyrite with quartz is reported from prospects on the vein.

The La Belle tunnel, owned by the Columbus Consolidated Mining and Tunnel Company, is opposite Whitecross post-office, on the south slope of the valley. Development has been carried on through a 650-foot tunnel running due south and a 130-foot crosscut to the southeast. This tunnel is located in a granite area and all the workings are in massive jointed granite. Three thin fissures were intercepted, the first trending east and west and the others shifting to the northeast. All are barren save the last, which is iron stained, but no ore was observed. It is said that the management is driving for a northeast vein that outcrops in the first ravine to the east.

The Silver Star property lies on the north side of the valley a short distance northeast of Whitecross. The workings are very old and at the time of visit were abandoned and inaccessible. Men who have worked in the tunnel, however, agree that it is about 100 feet in extent along a southwest vein. The rock at the surface and also underground belongs to the complex of tuffs and flows which fills the valley to the east. This mine is said to have produced a good grade of copper ore, consisting chiefly of gray copper with chalcopyrite. Specimens taken from the dump confirm this report and show in the vein considerable tetrahedrite and about equal amounts of chalcopyrite and pyrite, with a gangue largely of quartz. The walls are highly silicified fragmental rocks, probably tuffs, through which are sprinkled grains of pyrite and perhaps of tetrahedrite.

The Champion shaft is on the north side of Lake Fork, a few hundred feet east of the Silver Star. The property is now abandoned

and the shaft is full of water. Development, however, is known to have been carried to a depth of 160 or 170 feet, with an easterly drift of about 65 feet and one to the west of 30 or 40 feet. The rocks in the vicinity are dark porphyritic flows and fine tuffs, and the material on the dump is largely the same, but its identity is veiled by extensive mineralization. Deformation has produced a fissure trending approximately east and west, which may be observed at the surface and which it is believed the shaft and workings follow. Ore is said to have been taken from this fissure. It was of low grade, however, being valuable for copper, but containing excessive amounts of iron. Specimens collected from the dump, moreover, show the country rock to be greatly altered and silicified and also penetrated by pyrite. The vein material in these specimens contains chiefly chalcopyrite with pyrite and small amounts of galena, quartz and rhodochrosite being the gangue minerals. Of course this does not preclude larger amounts of valuable ore elsewhere in the vein, but the ore heretofore found was probably not valuable enough for profitable exploitation against a heavy flow of water.

The Napoleon shaft is located on the south bank of Lake Fork, nearly opposite the Champion shaft. It also is full of water and abandoned. It is reported to have been sunk 75 feet on an east-west vein. This vein at the surface cuts the igneous complex of flows and tuffs which form both the valley at this point and the country rock of probably the whole shaft. Ore of a good type, chiefly gray copper, is known to have been taken from this vein and shipped, but operations were discontinued because of water.

The Seward County property lies on the north side of the valley, just east of the Champion shaft. The mine is entirely abandoned and very little is known concerning its history. The claim seems to have been opened by short shafts and prospect tunnels, and it is reported vaguely that some gray copper and chalcopyrite ores were shipped years ago. The country rock is similar to that at the Champion, and the workings appear to have followed zones of silification and pyritization probably connected with fissuring.

The great Ohio mine is a mile and a half east of Whitecross, on the east side of Lake Fork, between Cooper and Silver creeks. At the time of visit this property was being more actively developed than any other in the vicinity. Work was progressing in a 200-foot tunnel which intersects an incline shaft from the surface about 100 feet long. A new shaft was also in progress a short distance east of the tunnel. The rock near the workings is commonly the quartz-bearing rhyolite mentioned as intruding and covering the fragmental complex. This proves to be also the rock underground. It has suffered considerable deformation through fissuring along approximately north-south lines,

and one of these fissures is followed by the main tunnel and incline shaft. Near the foot of the incline shaft the trend of the fissure is nearly due north, but farther in it turns to the northeast, and though in places it dips very steeply to the northwest or southeast, its general attitude is about vertical. Ore is found in this fissure in rather small shoots, which pitch to the north. Where examined the fissure was not over 3½ feet wide, and the ore was considerably broken, crushed, and mixed with gouge. This indicates strong movement since the deposition of the ore and closer examination shows that the ore occupies the interstices of older fissure breccia and has perhaps slightly impregnated the walls. The ore is chiefly galena and tetrahedrite associated with sphalerite, pyrite, and chalcopyrite, the whole being mixed with vein quartz. Thin sections of the fissure walls studied under the microscope show that mineralization, particularly silicification and pyritization, has penetrated for a considerable distance into the country rock. About 70 tons of ore have been shipped to date, and nearly as much more lies in the bins ready for shipment. The latter is estimated by the manager to contain 12 to 15 per cent copper, \$10 to \$12 in gold, 50 to 60 ounces in silver, and 10 per cent zinc. Since the fissure has never been followed to any great depth below the tunnel, it seems likely that other shoots, as large as the one excavated, might be uncovered at lower levels. Indeed, since the time of visit it has been reported that ore has been struck in the new shaft which was then being sunk for the purpose of intersecting this and like veins at greater depth.

The O. K. tunnels are located north of Lake Fork and several hundred feet west of Cooper Creek. They are short tunnels upon an east-west fissure system, but seem as yet not to have uncovered ore of any account.

CONCLUSIONS.

Where ore bodies assume a certain mode of occurrence, others of similar character, as a rule, occur in the same locality. Hence, in districts where ore is distributed in veins, as near Whitecross, the likelihood of discovering new veins is strong enough to give high encouragement to the prospector. Such veins, of course, are most evident on barren ridges and summits, but may be no less numerous and valuable, though not so easily found, on forest-clad slopes. Thus in the valley bottoms many lodes may lie in bed rock, hidden by débris, talus, or soil. The uniformly small size of the shoots in this area, however, leads to the expectation that new discoveries will not be more promising than those already made. It would seem that the small veins so far opened, as well as virgin property, might be more successfully exploited by a consolidation of interests. Moreover, the grade of the ore suggests that prospecting should not be carried on in a manner which precludes drainage by gravity.

THE GRANITE-BIMETALLIC AND CABLE MINES, PHILIPSBURG QUADRANGLE, MONTANA.[a]

By W. H. Emmons.

INTRODUCTION.

The Philipsburg quadrangle is a 30-minute area, which joins the south half of the Helena 60-minute quadrangle on the west. Its eastern border is about a mile west of Anaconda, and its northern border is just south of Stone station, on the Philipsburg and Drummond branch of the Northern Pacific Railway. During the summer and autumn of 1906 Messrs. F. C. Calkins and D. F. MacDonald were engaged in mapping the geology of the quadrangle, while the writer studied the ore deposits. The results of this work will be published later by the Survey. It is the purpose of this paper to give a brief description of two of the most important mines.

The thanks of the writer are due Mr. S. F. Emmons, in charge of the division of metalliferous ore deposits of the Survey, for valuable criticism and advice; to Mr. Paul A. Fusz and associates, of the Granite-Bimetallic mine; and to the Messrs. Bacorn and Mr. Adami, of the Cable. The courtesy of all the officers of these mines has made the field work more agreeable and their carefully kept maps and records have made it more effectual than it would otherwise have been. Inasmuch as this paper was written in the field, prior to the study of notes and collections, the writer reserves the privilege to revise statements and conclusions in the final report.

TOPOGRAPHY OF THE QUADRANGLE.

The Philipsburg quadrangle is for the most part mountainous and varies in elevation from 4,600 to 10,600 feet. The central portion of the quadrangle is drained by Flint Creek, which rises near Cable Mountain and flows northeastward to Missoula River. On both sides of this creek is a considerable area of relatively low hills, wooded only in part, which furnish good pasturage for cattle, and in the valley

[a] Preliminary paper, conclusions are subject to revision.

along the streams are a number of hay ranches, where the hardier grasses are cultivated. The higher country is thickly timbered with spruce and pine, sufficient for local needs but of too small size for the outside lumber market.

MINING DEVELOPMENT.

There are several mining camps within the quadrangle, of which the most important are Philipsburg, Cable, Georgetown, Princeton, Combination, Henderson, and Flint. (See fig. 1.) Some of these dis-

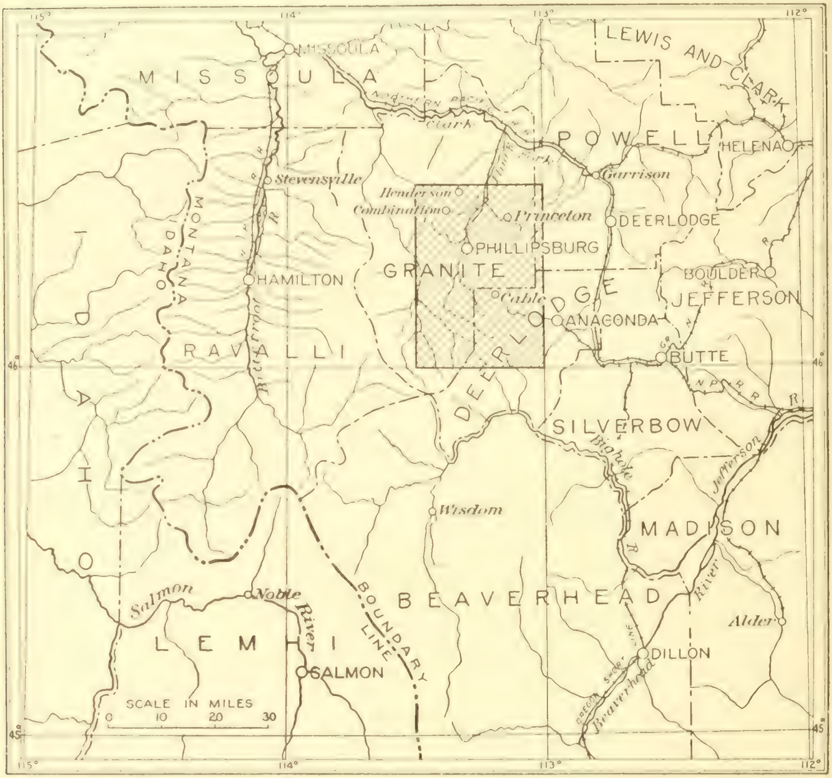

FIG. 1.—Index map showing position of mining camps in Philipsburg quadrangle, Montana.

tricts were among the first in Montana to receive the serious attention of quartz prospectors. In 1865 the St. Louis and Montana Mining Company, which was then operating a small smelter at Argenta, Mont., acquired mining claims near the summit of Hope Hill, about 1 mile north of Philipsburg. At great cost this company freighted in a 10-stamp pan-amalgamation mill from San Francisco and installed it at Philipsburg. This mill was still in operation in the summer of 1906, and is said to be the oldest mill in Montana. The Cable mine was discovered in 1866, and since then has been operated a great portion

of the time. The Trout, Algonkian, Two Percent, and a number of smaller mines, a mile or two east of Philipsburg, were opened soon after the Hope, and expensive reduction plants were built at the settlements of Hasmark and Tower near the mines. The annual production of the quadrangle, however, was relatively small until 1884, when the Granite mine, controlled by C. D. McLure and associates, became an important producer. A branch of the Northern Pacific Railway was built from Drummond to Philipsburg in 1887. Encouraged by the success of the Granite, a great deal of prospecting was done on various properties in the district, but none of these fulfilled the promise which they seemed to show except the Bimetallic, which was on the extension of the Granite vein.

The production of the mines in the Philipsburg quadrangle up to the present time is provisionally estimated at $45,000,000 to $50,000,000, more than half of which has come from the Granite mine.

GENERAL GEOLOGY.

The greater portion of the Philipsburg quadrangle is composed of sedimentary rocks which range in age from Algonkian to Cretaceous. According to the estimate of F. C. Calkins the thickness of the pre-Cambrian portion of the section is from 6,000 to 11,000 feet, and that of the later formations from the Cambrian to the Cretaceous is from 5,000 to 6,000 feet. The thickness of the entire section varies from 11,000 to 17,000 feet. Except for a probable angular unconformity between the pre-Cambrian and Paleozoic rocks, the beds are essentially conformable in dip, though unconformities of erosion occur at several horizons. The section, supplied by F. C. Calkins, is given below, the thicknesses being approximate and the correlations in some degree tentative:

Section of sedimentary rocks in the Philipsburg quadrangle, Montana.

	Feet.
Quaternary:	
Fluviatile deposits, consisting chiefly of rounded to subangular gravel and sand, spread on valley bottoms and forming terraces in the vicinity of Philipsburg.	
Glacial deposits: Moraines consisting mainly of granite bowlders.	
Juratrias and Cretaceous:	
Shales, sandstones, and quartzites, with some thin beds of gasteropod limestone	3,000+
Carboniferous:	
Quadrant(?) formation: Mainly quartzite; generally some red spotted shale at base; near Philipsburg a lower bed of pure quartzite separated by a layer of calcareous shale, impure limestone, etc., from an upper bed of less pure quartzite and sandstone; fossils, locally in red shale and limestone	200–500

Carboniferous—Continued.	Feet.
Madison limestone—	
Limestone, gray to white, mostly fine grained, rather thick bedded, locally cherty and containing some fairly thick beds of chert; fossiliferous	500
Limestone, fine grained, black on fresh fracture, blue-gray on weathered surface; usually flaggy, contains much chert as irregular concretions; fossiliferous; locally contains a bed of black shale near base	500
Devono-Silurian:	
Jefferson limestone: Massive, mostly white, but with many blue-gray to more nearly black beds; medium grained	1,000
Yogo limestone: Gray to white, medium thick bedded, with closely spaced, thin, siliceous to argillaceous laminæ, and locally a little limestone conglomerate, overlain by flaggy impure limestone, calcareous sandstone, and shale	400
Dry Creek shale: Near Cable, black to olive-green shale with a little gray-green, fine-grained sandstone; near Philipsburg, green to white banded calcareous shale	15–40
Pilgrim limestone: Fine grained, hard, usually cream-white, in part very light gray, locally contains thin beds of shale	200
Cambrian:	
Park shale: Calcareous, light olive-green to dark purplish brown, locally banded, very thin near Princeton and Philipsburg	15–50
Meagher limestone: Medium thick bedded, prevailingly medium grained, light blue-gray, nearly white or dark gray near base, gritty on weathered surface	400
Wolsey shale: Lower part olive-green to black, rather fissile, noncalcareous; upper part banded, calcareous	100–300
Flathead quartzite: Thick bedded, white to reddish, of medium to coarse texture	50–300
Pre-Cambrian:	
Camp Creek formation: Mostly deep-red shale, with some green in thin layers, grading into hard quartzitic reddish to white sandstone, which is very abundant in upper portion; shallow-water features	0–5,000
Blackfoot formation: Calcareous shale, impure limestone, and massive banded calcareous argillite, dark gray to light greenish gray on fresh fracture, weathering buff or yellow, grading into purer gray-weathering limestone, which occurs generally in subordinate amount interbedded with the shale in thin layers and as concretions	4,000
Ravalli (?) formation: Quartzite overlain by purplish and greenish-gray siliceous argillite	1,000
Prichard (?) formation: Bluish-gray argillites largely altered to mica schist, with interbedded sandstone	2,000 +

All the sedimentary rocks, except the glacial and fluviatile deposits, are cut by granite or by granite porphyry. The granite is composed essentially of feldspar, quartz, mica, and hornblende. One large body of it occurs about a mile east of Philipsburg, the western contact passing near the camps of Hasmark and Tower. This same mass extends southward as far as the Red Lion mine and eastward within

2 miles of the Powell mine. Another large boss of granite, not connected on the surface with this one, occurs just west of Cable and extends northwestward to the Southern Cross mine, and thence southward nearly to Silver Lake. An area much larger than either of of these overlaps the eastern border of the quadrangle, its western margin extending in a generally north-south direction from the head of Foster Creek to the head of Gold Creek. The granite of this mass forms the country rock of the Royal mine.

The granite prophyry has about the same composition as the granite, but contains more quartz. It forms several small masses of which the areal extent is insignificant compared with that of the granite. There is a typical occurrence of the granite porphyry about a mile north of Philipsburg, on the east slope of Red Hill.

Where the sedimentary rocks are in contact with the igneous intrusives, the limestones and shales have been greatly metamorphosed. The limestones have been altered to marble, which in many places carries more or less tremolite and white mica. The more calcareous shales have generally been changed to cryst lline aggregates, chiefly of garnet and pyroxene accompanied by more or less epidote, amphibole, magnetite, and quartz, while others have been changed to rocks rich in scapolite.

DISTRIBUTION AND GENERAL CHARACTER OF THE ORE.

The most important mining centers are those near Philipsburg, Cable, Combination, and Princeton, but there are a number of isolated mines in the country between these groups, and prospects showing ore are widely distributed over a large portion of the quadrangle. They are most numerous in the intrusive igneous rocks or in the sedimentary rocks near their contacts with the intrusives.

The valuable metals of the ores are silver, gold, and copper. Some of the ores carry considerable zinc and lead, but at present these metals are of no great economic importance to the miner. Magnetic iron ore is mined for flux. Some manganese oxide has been shipped for flux and to a less extent for its manganese content.

The ore deposits occur as fissure veins cutting both the granite and sedimentary rocks; as contact-metamorphic replacement deposits in limestone near the granite; and as replacement deposits in the sedimentary rocks, in part conforming with their bedding planes. From the standpoint of production the fissure veins are the most important. In the granite these are clear-cut fissures with good walls along which there has been practically no replacement of the country rock. In the sedimentary rocks they cut across the bedding at various angles, replacing limestones very irregularly and making large ore shoots at favorable places. The ore bodies of the Cable mine are the only known replacement deposits of contact-metamor-

phic origin. Several other mines near the Cable are located in the sedimentary rock near the granite contact, but in these mines the ore bodies so far as developed are distinctly replacement veins along fissures. One important group of replacement deposits is that of Hope Hill, where very siliceous silver ore occurs, for the most part as rudely tabular bodies in the bedding planes of limestone, but it also makes out from those horizons as relatively long, curved cylinders, crossing the bedding in all directions.

GRANITE-BIMETALLIC MINE.

HISTORY AND DEVELOPMENT.

The Granite Mountain and Bimetallic mines are about 2½ miles southeast of Philipsburg, on the steep western slope of Granite Mountain, which rises 3,000 feet above the valley of Flint Creek. Although controlled from the first by nearly the same interests and on the same ore shoot, they were worked separately, each with its own reduction plants, until 1898, when a consolidation was effected. Since that time the mines have been operated as one.

The Granite Mountain mine was first located in 1872, but the location was allowed to lapse and in 1875 it was relocated by E. D. Holland, J. W. Estell, and Josiah M. Merrell. In 1880 Charles D. McLure, then superintendent of the Hope mill, encouraged by assay of a specimen picked up from the dump, obtained a bond on the property for $40,000. After spending several thousand dollars in developing the block of ground between what is now level 1 and level 2, with fairly promising returns, he succeeded in organizing a syndicate of St. Louis investors, chiefly from the Hope directorate, who advanced him altogether $132,000. The mine was examined in April, 1881, by Prof. J. E. Clayton, who reported $75,000 worth of ore in sight, the vein being from 4 to 6 feet wide, with an average value of 44 ounces of silver. At this time tunnel (level) No. 1 had been driven 186 feet and No. 2 443 feet, tapping the ore shoot 300 feet from the portal. This ore was iron-stained quartz, carrying a small amount of silver chloride but relatively of low grade. Development work was continued steadily, and in 1882 and 1883 about 1,400 tons from levels 1 and 2 were milled at the Algonquin mill, at Hasmark, 1¼ miles northwest of the mine, a fair saving being made by dry crushing, roasting, and pan amalgamation. As exploration reached greater depth the oxidized ores became higher in grade and sulphide ores extremely rich in silver were found about 200 feet below the surface. Assured of sufficient reserves, the company built at the mine a dry-crushing stamp mill (mill A) with chloridizing roasting furnace, and soon followed it by one of larger capacity, making a total of 80 stamps. At this time the tenor of the ore milled was very high

and on level No. 6 an 11-foot face running 150 ounces in silver was left untouched for a considerable period, the mills being occupied with higher grade ore. From 1885 to 1892 the company was extremely prosperous, taking out about $20,000,000 in silver and gold, and paying dividends amounting to over $11,000,000. A third mill, with 100 stamps, was built at Rumsey, 1½ miles south of the mine, and connected with it by a wire tramway, and the Philipsburg and Drummond Railway was extended from Philipsburg to the mill, a distance of 7.7 miles. For a portion of this period the Granite Mountain was the most productive silver mine in the United States.

The property has been skillfully managed since the beginning of development. Specialists of broad training were employed in every department and the thorough organization enabled a high percentage of the output to be paid as dividends to the stockholders. Among the larger owners were Messrs. McLure, Rumsey, Fusz, Clark, Ewing, Filley, Lionberger, Shapleigh, and Taussig, all of St. Louis, and thus through this mine the foundations were laid for many of the larger fortunes of the Middle West.

The Bimetallic Mining Company was organized in 1882, Charles D. McLure, Charles Clark, and J. M. Merrell owning practically all the stock. Its plant was almost a duplicate of that of the Granite. A 100-stamp chloridizing mill was built at Bimetallic, on Douglas Creek about 1¼ miles above Philipsburg. This was connected by rail with the Philipsburg and Drummond Railway and by a wire tram with the hoist house. The mine had a large part of the same ore shoot that was exploited through the Granite, though the ore was hardly so rich. The production of the mine from 1883 to 1893 aggregated about $6,000,000, from which nearly $2,000,000 was paid as dividends. Owing to the fall in the price of silver the mine was shut down in 1893. A consolidation with the Granite was effected in 1898 under the name of the Granite-Bimetallic Consolidated Mining Company, with a capitalization of 1,000,000 shares. At this time the reserves of the Bimetallic mine exceeded those of the Granite, and accordingly the 200,000 Bimetallic shares were transferred for 600,000 shares of the new company, the 400,000 shares of Granite Mountain stock being traded share for share.

After the consolidation extensive improvements were made with a view to working the lower grade ores, of which there was still a large tonnage. An 8,850-foot tunnel from the canyon of Douglas Creek to the mine was completed, draining the Bimetallic mine at a depth of 1,000 feet and the Granite at a depth of 1,450 feet, thus greatly reducing the cost of pumping. A subsidiary organization, the Montana Water, Electric Power and Mining Company, built a reservoir covering several square miles on Georgetown Flat, near the head of Flint Creek, and installed an electric plant which supplied

the mines and mills with 1,100 horsepower. A 300-ton concentrator was built just below the collar of the Bimetallic shaft. From 1898 to 1904 the mines produced about $1,000,000 a year. In August, 1905, they were shut down on account of the low price of silver and the decreasing value of the ore. Subsequently they have been reopened above the drain tunnel and the leasing system has been adopted by the company. In the summer of 1906 about 100 men were engaged in the mines and in sorting the old Granite dumps.

The total production of the two mines has been something over $32,000,000 in silver and gold, from which nearly $15,000,000 has been paid in dividends; of this amount the Granite produced more than three-fourths and its dividends have been about $13,000,000. This represents net profits, since the original purchase price and other funds advanced by the syndicate were returned with interest and the extensive hoisting and reduction plants were built from the proceeds of the mine.

The mine was worked from five drift tunnels and two deep shafts, and is cut by a long adit which drains the Granite mine between levels 14 and 15, and the Bimetallic mine at level 10. The Granite (Ruby) shaft is about 1,550 feet deep, and the Bimetallic (Blaine) shaft is about 1,800 feet deep. The vein has been followed and stoped as far as 2,600 feet below the surface and there are altogether more than 20 miles of drifts and crosscuts. At present the mine is under water below the adit level.

GEOLOGY.

The country rock is a medium-grained granite, composed chiefly of feldspar, quartz, mica, and hornblende, which is cut by small aplite dikes. As a rule it is not greatly decomposed in the region of the veins, but is as solid there as elsewhere, although in many places in the walls of the veins the ferro-magnesian minerals have altered to green silicates for a short distance away. A considerable amount of the country rock is included in the vein as angular blocks broken from the walls and at numerous points the vein splits to inclose horses of the granite. The country rock has not been replaced by ore to any great extent, and the granite of the walls or horses can not be worked profitably. The walls are everywhere well defined and make a clear division between the vein and country rock.

ORE DEPOSITS.

General distribution of ore.—The Granite vein strikes about N. 75° E. and its usual dip is about 75° S., although in places it becomes nearly vertical or is even overturned, dipping toward the north. Its width varies from 1 to 20 feet. Along its strike it has been stoped for a distance of 4,500 feet and in depth about 2, 600 feet. As already stated,

the vein splits at many places, inclosing horses of various sizes, and here and there smaller veins make off from the principal fissure. Of these the "south vein," which branches from the main lode near the west end of the Bimetallic mine, is the most important, and a considerable portion of it has been stoped with profit. These minor veins do not appear to cross the main fissure, but join it, making angles nearly everywhere of less than 25°, which point toward the west. So far as known, all the minor veins lie to the south of the principal vein. Fig. 2 is a sketch plan of the lode.

In the eastern portion of the mine, on level 8, the vein splits into several branches, the line of separation being nearly horizontal. Below this level two of these branches reunite; others, however, diverge in depth.

The vein probably filled a fault fissure. There was movement along the plane of the vein before the fissure was completely filled and also after it was filled, but the amount of displacement can not be estimated. The fissure can not be identified with faults in the sedimentary rocks beyond the contact of the granite, and where it should

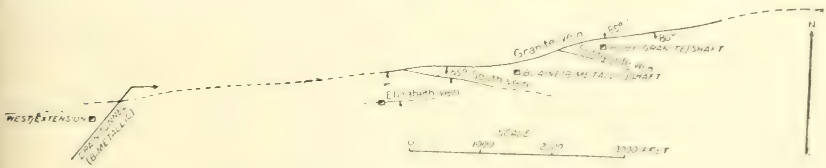

FIG. 2.—Sketch plan of the Granite-Bimetallic lode.

appear, if present, these rocks are not noticeably displaced. Postmineral movement is shown by the local brecciation of the vein and by the slickenside streaks of gouge along the walls. Much of this gouge contains angular fragments of broken quartz, and it is therefore, in part, at least, of postmineral age. That movement occurred while the vein was being filled is recorded by the numerous brecciated fragments of the country rock included in the veins.

So far as is shown by present exposures in the mine none of the postmineral movement has taken place along planes forming any considerable angle with the vein, and although the vein is exposed on many levels for nearly a mile along its strike at no place could cross faulting be detected.

Primary ore.—The primary ore, which is found in the lower portions of the mine, has a gangue of quartz and rhodochrosite inclosing a large quantity of pyrite, arsenopyrite, tetrahedrite, and tennantite, with some galena and zinc blende. Sparingly scattered through this ore are small specks of pyrargyrite, proustite, and here and there realgar and orpiment. This ore carries from 20 to 30 ounces of silver and from $1.50 to $3 in gold. Commonly broad bands of quartz alternate

with similar bands of the sulphides, and the banding is parallel to the walls of the vein. In many places the sulphides, chiefly pyrite and arsenopyrite, constitute half the volume of the vein, though quartz is as a rule more abundant than the sulphides. Much of this ore is fractured by movement that has occurred since it was deposited, and many of these fractures are healed by low-grade quartz and rhodochrosite. A seam of gouge, from 1 inch to several inches wide, generally occurs on one or both walls, and this is more pronounced where the vein itself is least fractured. More fragments of the country rock are inclosed in the ore on the lower levels than on the upper ones.

In the lower portion of the mine, about 2,600 feet below the surface, according to authentic records of the company, the vein was as strong and persistent as in the upper levels, and there was no indication that it was decreasing in width, although the values were uniformly low.

Enriched sulphide ore.—The secondary sulphide ore has a gangue of quartz and rhodochrosite, which contain or occur as alternating bands with argentite, proustite, pyrargyrite, tetrahedrite, tennantite, pyrite, and arsenopyrite. Galena and zinc blende are locally abundant; chalcopyrite and bornite are of rare occurrence. This ore carries from 50 to 1,000 ounces of silver and from $4 to $8 in gold. It extends nearly to the surface at one place and has been reported from level 17, but by far the greater portion of it occurs from 300 to 800 feet below the surface. Much of this ore is fractured and in many places the ribbonlike bands are faulted by minute normal and reverse faults, which are as a rule included entirely within the vein. This fracturing appears to have been produced along movement planes, which follow the vein very closely. Probably more than half the silver values of this ore are contained in dark ruby silver, or pyrargyrite, though light ruby silver, or proustite, is also an important ore mineral, as are also tetrahedrite, tennantite, and locally argentite. By far the greater portion of the ruby silver occurs in minute veinlets or seams filling cracks in the vein, as films on the outside of crushed vein material, or as crystals nearly an inch in diameter partially filling solution cavities in the vein. These solution cavities are in general rudely ellipsoidal in shape and, although not connected, their longer axes lie approximately in the same plane, which suggests that they are parts of a larger cavity which has been almost completely refilled. Clear quartz of later age than that of the remainder of the vein and occurring in many places as well-defined crystals pointing to the center of a druse is intimately associated with the ruby silver and like it is of more recent age than the bulk of the vein quartz. The lower portion of the zone of secondary ore does not uniformly carry high values in silver. Between levels 6 and 8 of the Granite, about midway between the

Ruby and Blaine shafts, the vein carried high-grade secondary silver ore, whereas on level 8, just below this ore, it was composed of rhodochrosite and quartz, cut by a large number of veinlets of zinc blende, chalcopyrite, and quartz. Here the rhodochrosite and early quartz is distinctly older than the zinc blende and chalcopyrite, for the vein was opened and locally brecciated in the interim between the deposition of these minerals. At this place the zinc blende and the chalcopyrite are related to the earlier minerals in the same way that ruby silver is above, and appear to play a similar rôle. It is probable that they were deposited at the same time, but that the zinc blende and chalcopyrite were carried down farther at this point by the secondary solutions. By far the larger portion of the dividends which the mine has paid came from the exploitation of the secondary sulphide ore.

Enriched oxidized ore.—Above the zone of enriched sulphides is a zone of enriched oxidized ore, for the most part between the 100-foot and 400-foot levels, but in a few places extending to the surface and at one place extending downward as far as level 9. This ore is composed of quartz stained with iron and manganese oxides and less commonly with copper carbonates. Cerargyrite and native silver occur as thin seams cutting through the quartz or as films plastered on the outside of crushed quartz fragments. Associated with this ore is a little argentite and pyromorphite; galena, zinc blende, pyrite, and chalcopyrite are of local occurrence. This ore runs from 300 to 400 ounces of silver and from \$5 to \$16 in gold. The value of this oxidized zone is in general less than that of the enriched sulphides.

Poor oxidized ore.—Extending from the surface down, in places as far as 300 feet or more, is a zone of poor oxidized ore, consisting of quartz, for the most part broken and stained with iron and manganese oxides. It contains some lead carbonate, malachite, azurite, chrysocolla, pyromorphite, pyrite, and galena. It carries less than 40 ounces of silver and only a little gold and has never been exploited with profit. This portion of the vein was so unpromising that the claims were once abandoned by prospectors, before the richer ores were discovered.

This oxidized zone has resulted from incomplete oxidation of the secondary sulphides. The apex of this zone, which is the apex of the vein, has been leached of the greater part of its silver and gold values, and this leaching appears to have extended in a few places as far as 400 feet below the surface. The presence of sulphides in this ore, however, shows that even here the oxidation is not complete. Small bunches of galena, with which a little argentite is probably associated, occur here and there in this zone and are unoxidized remnants of secondary sulphides. Some massive low-grade pyrite, which shows no sign of postmineral crushing, occurs similarly at this horizon and may

be a remnant of primary ore that was not involved in movement subsequent to veining and was therefore in a position unfavorable to enrichment. The low-grade pyrite crystals which occur locally in druses are of secondary origin and of more recent age than the massive pyrite of the vein.

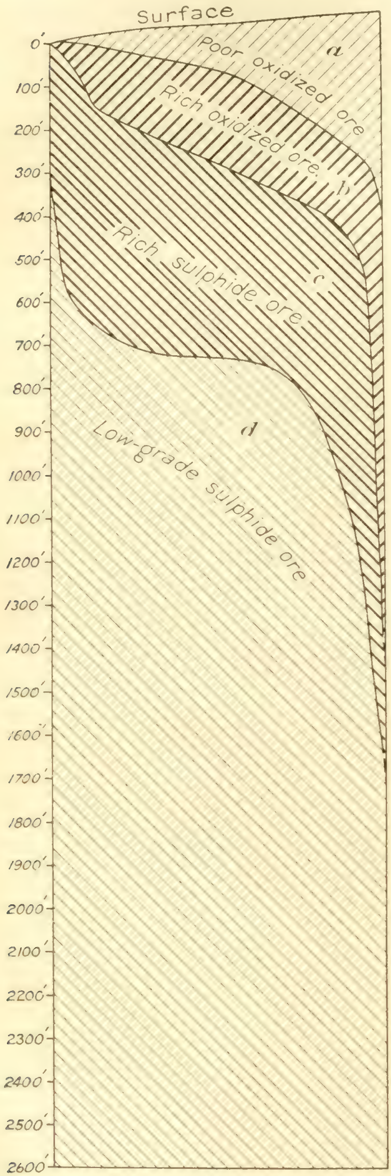

FIG. 3.—Generalized section of Granite vein, illustrating occurrence and association of minerals. *a*, Poor oxidized ore; *b*, rich oxidized ore; *c*, rich sulphide ore; *d*, poor sulphide ore. The horizontal position of the areas representing the various types of ore is without significance as to their position in the vein, but the areas show approximately the relative amount of each type at various depths. The width of the vein is greatly exaggerated with respect to its vertical extent.

Distribution of pay ore.—The manner of occurrence of ore in the vein is shown in fig. 3. In this figure no attempt is made to show the horizontal position of the various types of ore in the vein, but the areas show quantitatively the relative amounts of each type of ore at various depths. Each of these zones is cut by zones above it, and the upper zones descended farther where the brecciation of the vein favored the downward circulation of water. The pay ore is practically limited to the enriched oxide and the enriched sulphide zones, though a considerable amount of the low-grade primary ore has been mined.

The principal ore body is a tabular mass, in the main from 2 to 10 feet wide and about 4,500 feet long. The surface slopes to the west and consequently the greatest depth is obtained in the eastern portion of the mine, where the ore extends downward more than 2,600 feet below the surface. The west end of the ore body has been explored to a depth of about 1,600 feet. Between the eastern and western boundaries the ore is continuous in the upper levels, but in the lower levels a large part of the vein near the central portion of the mine is narrow or of too low grade to work. The form of the shoot of payable ore, therefore, is something like that of a flat arch, the ore pitch-

ing in both directions away from the keystone, which is assumed to be about 300 feet west of the Ruby shaft. The rich ore, however, is closely related to the topography of the country and occurs for the most part between 200 and 800 feet below the apex of the vein.

Where other veins unite with the Granite vein along a nearly vertical line, there are no marked effects of enrichment; but the richest portion of the vein occurs just above the union of several veins which joined along a nearly horizontal line. This is the great bonanza, east of the Ruby shaft, between levels 3 and 8.

Probable genesis.—The bonanza ores of the mine are unquestionably the result of secondary enrichment by descending waters; but it can not safely be assumed that the primary ores were everywhere even approximately of equal tenor. The great bonanza east of the Ruby shaft was very much richer than secondary ore occupying elsewhere a similar position in the vein, and probably resulted from primary ore of relatively high grade. The average of the low-grade ore in the lower levels of the mine carries about 25 ounces in silver. The average in the bonanza east of the Ruby shaft, as shown by annual mill runs, was about 175 ounces. This rich zone has an average vertical extent of about 400 feet, and if we assume that it has resulted from the enrichment of a primary ore carrying 25 ounces of silver in a vein of constant width, it would require 6 times 400 feet, or 2,400 feet of 25-ounce vein material, to produce this bonanza, and the original vein before denudation would then have had a vertical extent of at least 5,000 feet. Near the Blaine shaft, between levels 3 and 7, the ore averaged about 100 ounces for a vertical distance of about 350 feet. If this ore has resulted from the enrichment of 25-ounce rock, it would require the erosion of 1,050 feet of the vein from above its present apex, provided all of the values were redeposited. This would give a minimum vertical extent of about 2,850 feet for the original vein here before denudation. There has probably been more than 2,400 feet of erosion since the granite was intruded into the sedimentary rocks, for the Flathead quartzite, the earliest Cambrian formation, now outcrops at the contact with the granite. The entire Paleozoic section above the Flathead, as well as later sedimentary rocks, has probably been eroded from the quartzite since the intrusion. If the vein was formed soon after the solidification of the granite there has been ample erosion to account for any probable amount of enrichment, but as it is likely that the ore east of the Ruby shaft was primarily richer than that west of the Blaine shaft, an estimate below 2,400 feet, so far as the vein itself is concerned, appears to be safer. In either case the vertical extent of the vein was very great, and when this is considered, together with its persistence horizontally and its width in the lower levels of the mine, it appears very probable that the ore was deposited by ascending waters. The veins of the

group of which the Granite is the most important member cut both granite and sedimentary rocks, but do not extend very far from the contact. This points to the granite or to some later igneous rock below it as the probable source of the ores.

PRACTICAL DEDUCTIONS.

The country to the north, east, and south of the Granite-Bimetallic lode is traversed by silver-gold veins, which are smaller and of lower grade but otherwise of the same general character as the granite vein. Their strike varies less than 25° from east and west and in most places is a little north of east, approximately parallel to the granite vein. Nearly all dip more than 70° to the south. They traverse both the granite and sedimentary rocks and cross the contact, where they are commonly displaced by faults apparently of small throw. Their walls, like those of the Granite vein, are well defined in the granite but much less sharply defined in the sedimentary rocks, especially in the limestone, where they become replacement veins. At some places they are faulted by cross faults other than those at the granite contact. The Headlight vein, which cuts across the bedding of limestone, is displaced by a number of normal faults that follow the bedding planes of the limestone. The ore minerals are essentially the same as those of the Granite vein, though there appears to be a higher percentage of rhodochrosite in the veins where limestone is the country rock. Near the surface this alters to black manganese oxide, which has been mined to a small extent for that metal. The Trout vein is the most important of this group of silver veins and has produced several hundred thousand dollars' worth of ore.

Of the veins in the granite to the north of the Granite-Bimetallic lode a number have been prospected for more than a thousand feet along the strike, and considerable stoping has been done. None of them, however, has produced much more than $100,000 in silver and gold, and few have paid for the work expended on them. Though they are persistent along their strike, easily followed, and many of them of satisfactory grade, they are in few places of payable width.

From analogy with the Granite vein the depth at which the richest ore should be found in these veins is from 200 to 700 feet below the surface, and the tops of the richest ore shoots should be found not more than 400 feet deep and in most places much nearer the apex of the vein. Considerable prospecting has been done at this depth in secondary sulphide ores. In the country to the northeast and east of the Granite mine there are numerous outcrops of quartz veins that have been prospected only superficially. If there are shoots of rich ore in these veins, their highest point will likely be found almost invariably within 200 feet of the surface, though it is possible that the highest point of some will be 100 or in a few places even 200 feet lower.

In a number of places a sheeted zone of granite, produced by several closely spaced parallel fracture planes and containing a little crushed quartz, has been followed with the hope that the walls of the crushed zone will eventually inclose good ore. There is little basis for such a hope, since the sheeting is to a great extent, and probably in many places entirely, due to movement subsequent to veining.

North of Philipsburg, bordering on the area traversed by the fissure veins just described, are the bedding-plane replacement deposits of Hope Hill. They are of considerable economic importance and have produced several million dollars' worth of silver. These deposits are not discussed in this paper. The structural features of greatest economic importance in connection with them are the post-mineral faults, which cross them at a considerable angle with the bedding of the country rock. By far the greater portion of these faults are normal, which generally implies a downthrow of the hanging wall.

CABLE MINE.

LOCATION AND HISTORY.

The Cable mine is situated near the head of Cable Creek, about 8 miles southeast of the Granite mine and 13 miles northwest of Anaconda. It is 7½ miles above Browns Siding, the terminus of the Butte, Anaconda and Pacific Railway. It was discovered in 1866, and in 1867 the Nowlan mill was built, where 9,000 tons of ore were treated, giving a production of $172,000. According to Government reports the total production of the mine up to 1872 was $400,000. The placer just below the apex of the ore body was very productive, and in 1872 $18,000 was taken out in eight weeks. Some of the ore from the mine was unusually rich, and a single ton is said to have yielded $30,000. A nugget of gold from this mine, worth $375, was shown by Solon Cameron at the Centennial Exhibition.

In 1877, J. C. Savery bought the mine and built a new mill, which was operated until 1891. During this period more than $2,000,000 in gold was taken from the mine. The ore was free-milling and of good grade. Most of it came from the Cornish, Square Set, and Lake stopes, from 100 to 300 feet below the surface.

The ore shoots being apparently exhausted, the mine was idle from 1891 to 1900. Later the management was obtained by F. W. & H. C. Bacorn, who inaugurated a vigorous plan of development with a view to opening up new ore bodies in the lower levels. In their hands a moderate production has been sustained and considerable new ground has been prospected. The total production of the mine since discovery is from $3,000,000 to $4,000,000.

DEVELOPMENT AND EQUIPMENT.

A crosscut tunnel 888 feet long reaches the ore zone about 245 feet below the surface and continues along its general strike for about 2,000 feet. The width of this zone is from 80 to 360 feet, and it has been explored by a large number of crosscuts and raises from this level. There is an engine station about 1,600 feet from the portal of the main adit and a winze from which levels are run 65, 140, and 214 feet below the tunnel level. The lowest workings are a little more than 500 feet below the surface. Above the adit three levels are run from shafts now abandoned, and these workings are connected by stopes and raises with those below. The total development by crosscuts and drifts is about 7,500 feet.

The walls stand remarkably well and very little timbering is necessary. The huge cavities from which the ore has been removed have remained for years without sign of approaching collapse. Of these the Cornish, Square Set, and Showers stopes are above the tunnel level. The Cornish stope is a rudely cylindrical cavity just above the engine station, inclined toward the west about 30°. It is about 50 feet in maximum diameter, 125 feet long, and its top is about 65 feet higher than its base, which is just a few feet above the tunnel level. The Square Set stope is east of and above the Cornish stope, with the top of which its base is connected. Its plan is rudely elliptical and it extends upward within 50 feet of the surface. The Showers stope is about 100 feet west of the engine station, its base being that of the adit level. It is about 30 feet long, 15 feet wide, and 20 feet high. The Lake stope is a few feet north of the engine station and is a long, flat-lying opening, almost cylindrical in shape. It is 320 feet long, 40 feet wide, and from 15 to 30 feet high. Its roof is approximately at the level of the floor of the adit. On the 65-foot level there is a large stope below the west end of the Lake stope and connected with it, and there are several smaller stopes on the lower levels both east and west of the hoist.

The mine is equipped with air compressors, that furnish power for hoist, pump, and drills. Two diamond drills are operated continuously, since it is necessary to prospect the entire ore zone, which has an average width of about 200 feet. The cores, which aggregate several thousand feet, are kept accessible at all times and the records are carefully plotted in the office.

The mill is located just below the portal of the tunnel and is equipped with two Blake crushers and thirty Frazier & Chalmers stamps. A fair saving is made by simple amalgamation, even with the sulphide ores; the extraction is said to run from 80 to 90 per cent. In the autumn of 1896 experiments were made with a view to adding

concentrating machinery to the plant. The concentrates, though low in gold, carried sufficient copper and iron to make them a by-product of value.

GEOLOGY.

Country rock.—The ore deposits occur in the Wolsey shale and Meagher limestone. The Wolsey shale is in most places a rather fissile olive-green to black formation from 100 to 300 feet thick. The Meagher limestone is a thick-bedded medium-grained, nearly white to dark-gray limestone, somewhat gritty on weathered surfaces. Its usual thickness is about 400 feet. The Wolsey shale rests upon the Flathead quartzite and in turn is overlain by the Meagher limestone. The relation of these rocks with later ones is given in the geologic section (p.p 33–34).

These formations have been cut by two intrusive masses of granite in such a manner as to form a long narrow belt of sedimentary rocks, chiefly Meagher limestone, closely confined between granite walls. The southwestern granite mass covers an area of several square miles and extends nearly to the Southern Cross and Gold Coin mines. This granite body forms the south wall of the ore zone. The northern intrusive is much smaller and its outcrop is relatively long and narrow, so that its form suggests that of a dike approximately parallel to the contact of the larger mass. These two intrusives are in the main from 50 to 360 feet apart, and though each sends off small apophyses toward the other, connection between the two has not yet been found. The strike of the ore zone, as determined by the granite contacts which limit it, is about northwest. The attitude of the sedimentary rocks in the mine can not everywhere be made out, but their general strike is probably close to that of the ore zone and, locally at least, their dip is nearly 90°. The granite is medium grained and composed essentially of feldspar, quartz, mica, and hornblende. It is in most places fresh and very much resembles the granite that forms the country rock of the Granite mine, near Philipsburg, though the two bodies are not connected in outcrop.

Contact metamorphism.—The sedimentary rocks are greatly metamorphosed near their contact with the granite. The upper part of the Wolsey formation is a calcareous shale and changed very readily to a rock composed chiefly of pyroxene, amphibole, garnet, magnetite, epidote, and mica. Rocks of this composition outcrop on the surface north of the ore zone, and angular masses of garnet rock more than a foot in diameter occur at several places in the lower levels of the mine. They are especially numerous on the north wall of the 214-foot level. The contact-metamorphic minerals, especially garnet and epidote, are in many places concentrated along the bedding planes of the altered shale to a certain extent, and this is also true of pyrite.

The Meagher limestone has been extensively recrystallized near the granite intrusive, and within the entire ore zone it has been changed to a marble of which the grain varies greatly. The commonest facies is a white or light-gray marble composed of interlocking grains of calcite that are a little smaller than grains of wheat. Very commonly this grades into a marble composed in the main of interlocking crystals of calcite several inches in diameter. As the grain of the marble increases a considerable proportion of quartz, iron oxides, and iron and copper sulphides begins to appear, and in the coarsest varieties these minerals are as a rule present in considerable quantities. The coarsely crystalline calcite occurs throughout the ore zone, but is most abundant near the granite contacts.

Magnetite is present throughout the ore zone as large, irregular bodies that have apparently no relation to the bedding planes of the rocks. These bodies are confined to the limestone and occur on all levels. The magnetite bodies are rudely ellipsoidal in outline, and some of them are at least 100 feet in diameter. One of the larger masses lies just west of the engine station and forms in part the west wall of the Cornish stope.

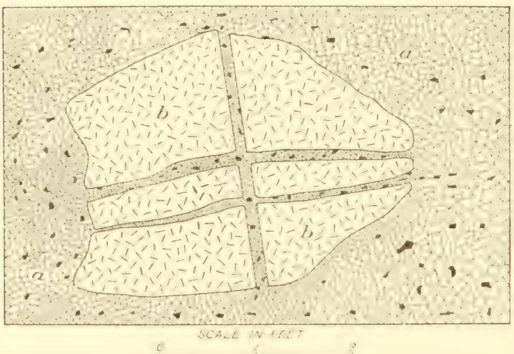

FIG. 4.—Granite block surrounded and cut by coarsely crystalline calcite, quartz, pyrite, and chalcopyrite, 40 feet below northwest end of Lake stope, Cable mine. *a*, Calcite, quartz, pyrite, and chalcopyrite; *b*, granite.

Mica veins.—Veins composed of green mica occur in many places at the contact between granite and limestone or magnetite and limestone, and apart from the contact they have been noted cutting the magnetite. These veins are from 1 to 3 inches wide and are composed of crystals of green mica about an inch in diameter. They are probably of pegmatitic origin and are of later age than the granite and the magnetite, and they may represent an end phase of the granitic intrusion.

Age relations.—The general relations of the various rocks, as shown by their contacts, can be briefly stated. Shale and limestone are the earliest rocks, and limestone is cut by granite and magnetite and by veins of mica pegmatite. Granite cuts the sedimentary rocks only and does not cut magnetite. Magnetite cuts limestone and probably follows the granite in age. The mica veins cut all the other rocks and are therefore of later age.

The recrystallization of the limestone continued after the granite had solidified and had been fractured. Numerous veins of the calcite cut the granite. Fig. 4 shows a block of granite 40 feet below the

northwest end of the Lake stope; it is about 3 feet in diameter and is completely surrounded by coarsely crystalline calcite containing quartz, pyrite, and chalcopyrite and is cut by veins of the same material from 1 to 3 inches wide. Similar veins cut the limestone and more sparingly the magnetite. The coarsely crystalline calcite grades into the limestone and commonly the contact is frozen so tightly that in milling it is necessary to treat a considerable amount of barren limestone with the calcite ore.

Fissures.—Fissures, later than the ore, cross the ore zone at several places. On the tunnel level, 250 feet southeast of the engine station, a fault striking N. 70° E. dips to the east about 70°. East of the fault the southern contact of granite and limestone has moved about 18 feet to the north. Other fissures cut across the ore zone at various angles, but the displacement along them is not great. Most of these fissures carry a few inches of gouge, but are not mineralized. There are also faults of earlier age than these, but later than the granite intrusion. It is not possible to follow these earlier fissures in the coarsely crystalline calcite on account of complete recementation, and they are probably more numerous than they appear to be. The brecciation of the tongues of granite is of the same age as this fissuring, which probably occurred soon after the granite became hard but before it became cold, since there was much recrystallization afterwards. These fissures are healed by coarsely crystalline calcite and quartz; the principal ore bodies do not appear to be related to them, however, but are altogether irregular in outline.

ORE DEPOSITS.

General character.—The ore deposits are large, irregular bodies of calcite and quartz, containing a large amount of mixed iron and copper sulphides and iron oxides. These are confined to a long, narrow zone of limestone and calcareous shale that trends southeastward and is bounded by two granite intrusives, the walls of which are steeply inclined, nearly parallel, and from 80 to 360 feet apart. The nonmetallic minerals are calcite, quartz, barite, and dolomite, of which calcite is most abundant. The original metallic minerals are pyrite, chalcopyrite, pyrrhotite, arsenopyrite, magnetite, specularite, and gold. Marcasite should perhaps be placed in this class, also. The secondary metallic minerals are hematite, limonite, manganese oxide, siderite, malachite, azurite, chrysocolla, bornite, chalcocite, gold, and copper.

In most of the ore of the lower levels calcite, quartz, pyrite, and chalcopyrite are interlocking, irregular bodies, which apparently were deposited at one time. When a magnet is passed over the crushed ore, there is nearly always a separation of magnetite and

pyrrhotite. Though the source of the calcite is the limestone or country rock, the calcium carbonate has migrated to a certain extent and has been redeposited with the other minerals.

Gold occurs finely disseminated in calcite, quartz, pyrite, pyrrhotite, and chalcopyrite, as large nuggets associated with these minerals or, less commonly, as thin sheets following the cleavage of calcite.

In the table on page 55 comparisons are made of the minerals of the Cable and Granite-Bimetallic mines.

As already stated, the valuable ore deposits are confined to the sedimentary rocks. The calcite stringers which cut the granite are small and of low grade and have never been considered of economic value. The ore is so irregularly distributed in the sedimentary rocks that the entire zone is regarded as the vein, and must be prospected from wall to wall by crosscuts and drill holes in order that no ore bodies shall be overlooked. This ore zone strikes southeastward, is rudely tabular and nearly upright, and has been partially explored underground for about 1,800 feet along its strike; on the surface it appears to extend farther northwest along the same general course; its vertical extent is unknown, but has been proved for about 600 feet. On the tunnel level the walls or granite boundaries are for the most part about 210 feet apart and nearly parallel. The contact plane of the north wall dips 80° to 90° NE. The plane of the south wall is very irregular and from the tunnel level, near the engine station, has a low dip northeastward to the level 65 feet below, so that at this point the ore zone is only about 80 feet wide. Below the 65-foot level the contact dips again to the southwest, so that the ore zone is about 125 feet wide below this point, on the 214-foot level.[a] The outline of the ore zone is irregular also on account of the small tongues of granite that project into the limestone and the blocks of granite that are portions of such tongues detached and broken by subsequent movement.

The recrystallization of the limestone into medium-grained or coarser marble is general; and in this metamorphism the entire ore zone was involved. The formation of the coarse calcite or ore may have occurred, to a considerable extent, along structural lines, such as planes of early movement and bedding planes, but if so these were apparently so irregular and complex that they can now be traced only in exceptional cases and then only for short distances. On the 214-foot level in at least one place the ore followed for a short distance what appeared to be the original bedding planes of the limestone. That the coarsely crystalline calcite or ore in some places follows lines of movement is shown on the tunnel level, just east of the entrance to the Lake stope. Here three flat, nearly horizontal bodies of granite occur at different elevations and in positions which show them to be

[a] Recent drilling shows that it is much wider than this east of the shaft on this level.

broken pieces of a larger mass; the lines of faulting by which they were separated have been entirely obliterated and the blocks are now surrounded by coarse calcite; the planes where the faults once passed show no signs of movement, but are completely recemented by coarse calcite, in every way resembling that which surrounds the granite blocks elsewhere. Since the faulting, the recrystallization has been complete.

The primary ore is the coarse calcite carrying a variable amount of quartz, pyrite, chalcopyrite, pyrrhotite, arsenopyrite, magnetite, hematite (specularite), and gold. These minerals appear to have been deposited at the same time and each of them has been noted in the lower levels of the mine. The metallic minerals as a rule occur as irregular masses in the spar and quartz, but locally as bands alternating with them. In this ore the gold is for the most part finely disseminated in the rock, but rich ore containing masses of gold larger than a grain of wheat has been found on the lowest level of the mine. Some of the larger bodies of gold may be of primary origin. A mine specimen as big as a walnut contains about half pyrrhotite and half gold. The association of oxides and sulphides is common in all of the ores from all parts of the mine. In the lowest level copper ore is found in which films of bornite and chalcocite coat masses of chalcopyrite. There is a considerable quantity of this ore along the north granite contact on the 214-foot level.

The oxidized ore has so far proved the richest of the mine. This occurs near the tunnel level and in the ground above it and is characterized by a large amount of hematite and limonite. It contains more silica and less calcite than the sulphide ores. Some of the oxidized ores from the upper workings carried considerable copper, and several thousand tons of tailings from ore milled years ago, before the present mill was built, were found to pay handsomely when smelted for their copper content. The average of analyses of seven cars of these tailings shipped to the Anaconda smelter is as follows:

Average analysis of tailings from the upper and partly oxidized ores in Cable mine.

Silver	ounces per ton	0.15
Gold	per ton	\$2.97
Copper	per cent	3.06
Insoluble matter	do	19.1
FeO	do	38.3
CaO	do	10
Moisture	do	11.2
CO_2 (estimated)	do	8

Tailings from sulphide ores milled later and from lower levels do not carry such high values in copper, so it appears that there was a copper-enriched zone in the upper part of the mine. The sulphide copper ore on the 214-foot level is, however, still richer in copper than the tailings from the ore near the surface.

Distribution of ore in the deposits.—The distribution of ore in the ore zone is extremely irregular. The largest and richest body of ore was the Cornish ore shoot, a rudely cylindrical mass inclined from the horizontal toward the west, and occupying approximately the Cornish stope, described on page 46. Above this and connected with it is the Square Set ore shoot, which continues upward at a steeper angle to the surface. The Showers ore shoot, about 100 feet west of the engine station, is in line with the other two, but a large irregular body of magnetite is situated between them. The magnetite forms the northwestern boundary and a part of the base of the Cornish ore body. The three ore bodies appear to be connected to the south of the magnetite body by coarsely crystalline calcite and quartz. The plane of these ore bodies is near the center of the ore zone and makes a small angle with its strike, trending more nearly east and west. Still another group of ore bodies occurs to the north of this one, lying close to the north Granite contact. It is not connected by ore with the Cornish group. Of the northern group the Lake ore shoot is by far the largest and most productive. The shape of this ore body was nearly that of a thin cylinder about 320 feet long—approximately the shape of the Lake stope, described on page 46. Its northwest end is connected by low-grade sulphide ore with an ore body just below and a little farther north on the 65-foot level, below which there are still others on the 140-foot and 214-foot levels. In these, however, the ore does not extend eastward as far as in the Lake ore body. All the ore bodies of this group are closer to the northeast wall than to the southwest wall and are north of and below the Cornish group. The Square Set and Cornish stopes are connected by ore, as are the Lake stope and the stope on the 65-foot level. If the central point of each of the ore bodies is plotted not more than three such points fall in approximately the same plane. Since any three points have a common plane, it is clear that the ore bodies are not related to a plane like ore shoots in a fissure vein. The ore occurs in general a few feet away from the granite, and only in the Lake stope and its continuation on the level below did the stoping extend to the granite. Owing to the close confinement of the ore zone between the granite walls no point in the zone is more than 200 feet from granite.

Genesis of the ore.—The form and general character of the ore bodies show that they are replacement deposits. They can not be classed as replacement veins or stocks, for their boundaries are approximately cylindrical or rudely spherical, and a single ore body does not extend very far in any one direction. Taken as a whole they show little or no alignment.

Of the minerals of contact-metamorphic origin amphibole, calcite, garnet, mica, and epidote are present in the ore zone; but of these, so

far as can be determined megascopically, calcite alone is intimately associated with or is a part of the ore. Among the primary ore minerals those characteristic of deposits of contact-metamorphic origin are pyrite, pyrrhotite, chalcopyrite, magnetite, and specularite. In many respects the ore bodies resemble the copper deposits of the Clifton-Morenci district in Arizona, for which Lindgren has proved a contact-metamorphic origin.[a] So far as the ore itself is concerned the association of minerals is much the same. The chief difference is that the Cable ores carry considerable gold and less copper than those of the Clifton-Morenci district. The bodies of magnetite, the mica veins, and the ore deposits all appear to owe their origin to the intrusion of the granite. The magnetite represents a phase of contact metamorphism when substitution was complete or nearly so. The mica veins probably represent an end phase of igneous intrusion, since they occupy slip planes which were made after the granite had become hard and after the magnetite bodies had formed. The coarsely crystalline calcite, carrying ore, has resulted partly from substitution and partly from recrystallization of the country rock. Silica, iron, sulphur, copper, and gold were added and some lime was probably removed. This ore has certainly been extensively recrystallized since the granite became hard enough to break. Fault fissures that cut both granite and calcite have been completely healed in the calcite in such a manner that their presence would not even be suspected if this rock alone were exposed. Small calcite veins also cut the granite. Though the substitution or replacement probably occurred while the granite was still soft, recrystallization on an extensive scale continued after it had solidified.

PRACTICAL DEDUCTIONS.

The granite comes in contact with limestone at several places around Cable Mountain, and bodies of magnetite similar to those of the Cable mine are not uncommon. Near the granite at several places are ore deposits in limestone that are of considerable importance; but these, so far as present developments show, are not of the same type as the Cable, being replacement veins of very irregular width, yet clearly related to fissures. The ore is much the same as the oxidized ores of the Cable, the ore minerals being limonite, hematite, specularite, and magnetite, with a little pyrite and pyrrhotite. The values are chiefly in gold. They are almost invariably largest and richest at the bend of a fissure or at the intersection of two fissures.

Iron-oxide gossans are very common in the vicinity of Cable Mountain, but in most places they carry very low values in gold or are barren. These iron caps have resulted from the oxidation of an ore

[a] Lindgren, W., Copper deposits of Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, pp. 126–164.

composed in part of pyrite, for many of them contain pseudomorphs after that mineral. The gold of the replacement veins, so far as they have been developed, is finer than that of the Cable mine, and there are no placers of importance. Good ore bodies have been found below barren or low-grade gossans; but thus far the highest points of the ore shoots have everywhere extended within 50 or 100 feet of the surface and at most places nearer. The trend of these veins can usually be made out by trenching or by digging shallow pits. The most favorable place for prospecting is at the intersection of two veins.

Much of the magnetite carries from 20 to 80 cents a ton in gold, and at some places it has been prospected with the hope that in depth it will change to a sulphide ore carrying gold of payable grade. The large bodies of magnetite, however, are unquestionably of primary origin and will continue to be magnetite as far down as they extend. The pyrite ore of the veins alters to limonite and hematite, carrying small grains of magnetite and nowhere to large masses of magnetite. The presence of the small magnetite grains in the oxidized ore has no diagnostic value, for they are present in the oxidized ore of practically every ore deposit in the Philipsburg area, and a large number of these are ordinary fissure veins and in no sense replacement deposits.

RÉSUMÉ.

The Granite-Bimetallic lode is a typical fissure filling of simple structure and of remarkable persistence both horizontally and vertically. Surface waters have leached the values from its apex and to a variable depth of 50 to 300 or 400 feet below the surface. Below this zone is one of enriched oxidized ores in which the values are largely horn and native silver. Next below is a zone of enriched silver sulphides, unquestionably of secondary origin, and the primary ore, the deepest in the vein, is a low-grade sulphide ore carrying silver and gold.

The Cable ore body is a contact-metamorphic deposit of rather uncommon character, but resembles most such deposits in having no definite shape. The country rock is for the most part limestone and has undergone the usual change due to contact metamorphism. The ore minerals, aside from the presence of considerable coarse gold, are those commonly associated with ores of contact-metamorphic origin. As a rule the ore is not immediately at the contact of the granite, but may occupy any position in the ore zone.

So far as their larger structural features are concerned the ore deposits of the two mines are so unlike that they can scarcely be compared. A list of nearly all the minerals noted in the two mines, with short notes upon their occurrence or position in the deposits, is given in the subjoined table. This list was made previous to micro-

scopic study, and other minerals should doubtless be added to it. Forty minerals or varieties are noted. Of these 25 per cent are peculiar to the Cable, 25 per cent peculiar to the Granite, and 50 per cent are common to both mines.

Comparison of minerals in the Granite-Bimetallic and Cable mines.

Minerals.	Granite-Bimetallic mine (a silver-gold fissure vein in granite), 2,600 feet deep.	Cable mine (a gold-copper contact-metamorphic deposit in limestone and shale at contact with granite), 600 feet deep.
Oxides.		
Limonite	In upper levels	In upper levels.
Hematite	do	Do.
Specularite	None	Throughout the mine.
Magnetite	Sparingly present in upper levels	Very abundant on all levels.
Manganese oxide	Considerable in upper levels	A little in upper levels.
Native metals.		
Gold	Finely divided throughout the mine	Large nuggets chiefly in upper workings; small anhedra on all levels.
Silver	In upper levels	No native silver noted.
Copper	None	A little in upper levels.
Carbonates.		
Calcite	Very sparingly present	Very abundant on all levels.
Rhodochrosite	Considerable	None.
Siderite	None	A little.
Dolomite	A little	Do.
Malachite	In upper levels	In upper levels.
Azurite	do	Do.
Sulphate.		
Iron sulphate	Common as crystals on walls	Common as crystals on walls.
Sulphides.		
Pyrite	Abundant	Abundant.
Pyrrhotite	None	At many places.
Marcasite	do	A little.
Chalcopyrite	A little	At many places.
Bornite	do	Do.
Argentite	At many places	Some.
Chalcocite	Little or none	A little.
Arsenopyrite	Abundant in lower levels	A little in lower levels.
Ruby silver (pyrargyrite and proustite).	At all depths below 200 feet, but less abundant in lower levels.	None.
Gray copper (tetrahedrite and tennantite).	In lower and middle levels	Do.
Galena	At many places	Rare.
Blende	do	Do.
Realgar	Here and there	None.
Orpiment	do	Do.
Silicates.		
Quartz	Very abundant	Much less abundant than in Granite-Bimetallic mine.
Rhodonite	At many places	None.
Chrysocolla	In upper levels	In upper levels.
Actinolite	None	At many places.
Wollastonite	do	Here and there.
Garnet	do	Do.
Green mica	do	At many places.
Epidote	do	Here and there.
Kaolinite	Abundant	Not so abundant as in Granite-Bimetallic mine.

GOLD-BEARING RIVER SANDS OF NORTHEASTERN WASHINGTON.

By Arthur J. Collier.

INTRODUCTION.

The occurrence of finely divided gold associated with magnetic iron in the sands of Snake River, in Idaho, is well known, and published reports describing these deposits and the methods of mining and collecting the gold have frequently appeared. Information regarding the presence of similar gold along the Columbia and other of its tributaries is not so general, though such occurrences have been known locally for many years.

From twenty to thirty years ago placer claims were worked at many points along the upper Columbia by Chinese,[a] but since the exclusion of Chinese laborers these old mines have been abandoned and the evidences of them are obscured by a growth of young pine trees. Mining was resumed to a certain extent by white men during the hard times of 1893 and 1894, when, as reported, scant wages could be obtained, but in later years the attempts to extract this gold have been sporadic and usually ineffectual. Interest in these deposits has recently been revived by the location, ostensibly for placer-mining purposes, of many large tracts of bench land adjacent to Columbia and Sanpoil rivers in the Colville Indian Reservation.

During the past season an investigation was made by Mr. F. M. Goodwin, of the General Land Office, and the writer, to determine whether or not these locations were made in good faith. This investigation was confined to 100 miles of the Columbia Valley from Nespelem to Kettle Falls and to the Sanpoil Valley below Republic, but much of the resulting information is believed to be of sufficient general interest to warrant publication.

GEOGRAPHY.

The Colville Indian Reservation lies in the northeastern part of the State of Washington, north of Columbia River, which bounds it on the east and south sides. This river flows southward from the Canadian

[a] Symons, Thos. W., Rept. on Examination of Upper Columbia River: Senate Ex. Doc. No. 186, 47th Cong., 1st sess., Washington, 1882, pp. 27–28.

boundary for about 90 miles to its junction with Spokane River, where it turns sharply and flows westward for 80 miles to the mouth of the Okanogan, which has a southerly course from the Canadian line and forms the western boundary of the Reservation. Sanpoil River flows across the reservation, also in a north-south valley, joining the Columbia about halfway between the Okanogan and Spokane. At the mouth of the Okanogan the Columbia again turns to the south and, a short distance beyond, to the east, flowing in that direction to its junction with Snake River and partially surrounding an extensive plateau region known as the Big Bend country.

The Colville Reservation comprises about 2,000 square miles, a large part of which is agricultural and timber land, nearly all of the remainder being valuable for grazing. It is only partially settled by Indians, is ill supplied with wagon roads, and is not reached by rail, though an electric line is under construction from Spokane to the Columbia at the mouth of Spokane River, and several surveys have been made and rights of way located for a railroad through the Sanpoil Valley.

Columbia River below Kettle Falls is navigable by steamboat except for a rapid at the mouth of Spokane River.

The Big Bend country south of the reservation is nearly all in cultivation. It is traversed by the Great Northern and Northern Pacific railways. The region east of the reservation is also well settled and is reached by the Spokane Falls and Northern Railway. The country between the Colville Reservation and the Canadian boundary was formerly included in the reservation and has been open to settlement for only a few years. Republic, its principal town, is at the head of Sanpoil River and is the terminus of a branch line from the Canadian Pacific Railway.

TOPOGRAPHY.

The Big Bend country which lies south of Columbia and Spokane rivers is a plateau 2,000 to 3,000 feet above the sea, characterized by slightly rolling topography and here and there traversed by dry canyons called coulees. This plateau is mantled by fine-grained, light-colored soil and comprises a large part of the wheat lands of Washington.[a]

North of Columbia and Spokane rivers the topography is more diversified. Although upland-plain surfaces are not lacking, these are surmounted by two ranges of higher hills which extend north and south on either side of the Sanpoil and which attain maximum elevations of about 9,000 feet near the northern boundary of the reservation. Columbia, Sanpoil, and Okanogan rivers all flow in deep canyons from 1,500 to 2,500 feet below the general level. Grand Coulee, a dry

[a] Calkins, F. C., Water-Sup. and Irr. Paper No. 118, U. S. Geol. Survey, 1905, pp. 45–49.

canyon about 500 feet deep, extending southwestward from the Columbia across the big-bend plateau is another remarkable feature which must be considered in any discussion of this region.

The Columbia and Sanpoil valleys, to an elevation of 1,500 feet above the water, are characterized by broad terraces of silt and gravel. The upper terrace is in most places well marked. South of the Columbia it extends for short distances up many of the small tributary canyons, which widen out into straths at this elevation. A very noticeable example of these straths is seen on the road from Wilbur to Clark, which follows a small canyon that at the level of this terrace widens out into an attractive little valley containing one or more farms. North of the Columbia the topography previous to the terracing was of an older type, and many of the upper terraces extend for several miles away from the river in the valleys of tributary streams that flow in deep canyons with silt and gravel walls. The lower terraces, although nearly as extensive as the upper, are more irregular and are not easily correlated with one another. Although they occur at various elevations most of them are between 20 and 300 feet above the river. Bench lands of this type, especially at the lower elevations, are in many places easily irrigated from small tributary streams. Such lands south of the Columbia are used almost exclusively for fruit culture and are valued at $40 to $400 an acre.

GEOLOGY.

GEOLOGIC FORMATIONS.

Nearly all the rocks north of the Columbia and in the bed of its canyon are schists or intrusives of various kinds, which probably range in age from lower Paleozoic to early Tertiary. They have not yet been studied in sufficient detail to differentiate the areas of the various types. South of the Columbia these crystalline rocks are buried beneath basalts and interbedded sediments of Miocene age, which have been described as the Yakima basalt.[a] Generally these basalts terminate at the south side of the Columbia gorge, though there are a few small areas within the Colville Reservation capped by them. East of the reservation the basalts extend a few miles north of Spokane River, where they overlap, the crystalline rocks thinning out at their northern edge. The sands, silts, and gravels forming the benches and terraces along Columbia and Sanpoil rivers constitute the youngest formations in the region. In general the upper terraces are composed of fine, light gray or brown silt and sand containing only a small percentage of gravel. As will be shown, they are indirectly the products of glaciation. The sediments of the lower benches contain more or less false-bedded gravel and sand and are river deposits

[a] Smith, G. O., Water Sup. and Irr. Paper No. 55, U. S. Geol. Survey, 1901, pp. 15-17. Calkins, F. C., Water-Sup. and Irr. Paper No. 118, U. S. Geol. Survey, 1905, pp. 30–45.

of more recent origin. Near the west end of the reservation there are many erratic bowlders and other indications of a glacier which moved down the Okanogan Valley from the north and spread out over the big-bend plateau to the brink of the Grand Coulee.[a] The valley of the Okanogan and the plateau south of the Columbia at this point are said to be strewn with glacial drift. Small areas of bowlders, probably the terminal moraines of valley glaciers, are found in the Sanpoil Valley about 50 miles north of the Columbia and in the Columbia Valley a few miles north of the mouth of the Spokane.[b] In the latter locality the moraine appears to be older than the terraces by which it is apparently overlain.

GEOLOGIC HISTORY.

The geologic history of the development of these topographic forms is interesting and may be briefly summarized here. Previous to the middle of the Tertiary period the drainage of northern Washington was developed. Columbia, Sanpoil, and Okanogan rivers flowed southward across the big-bend country, converging at some point now buried beneath the basalts.[c] Then followed a period of volcanic disturbance; the earth's crust south of the Columbia was fissured and great volumes of lava poured out and spread in sheets over the surface, burying the old surface beneath thousands of feet of new rocks. The pre-Miocene valleys were filled, and the Columbia was diverted to a new channel around the northern edge of the lava field, intercepting the valleys of the Sanpoil and Okanogan as it does now. After the volcanic period the whole region was probably elevated and these rivers cut gorges nearly if not quite to the present depth. Later the Okanogan glacier completely dammed Columbia River, forming in its upper valley a lake that extended for many miles. The waters of this lake spilled southward along the east side of the Okanogan glacier, cutting the 500-foot gorge known as the Grand Coulee,[d] whose bed at its upper end is cut into the crystalline rocks below the basalts. It is estimated to be from 1,000 to 1,500 feet above the river and indicates approximately the depth of water before the lake disappeared.

While the glacier remained the lake thus formed was nearly filled with sediments, the remnants of which form the higher terraces and benches above described. The upper terrace of the Columbia is reported to be continuous with a stream terrace in the Grand Coulee. When the ice barrier disappeared, the river resumed its former course,

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[a] Russell, I. C., Geological reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893, pp. 87–89. Smith, G. O., and Calkins, F. C., Bull. U. S. Geol. Survey No. 235, 1906, pp. 35–41. Salisbury, R. D., Am. Geologist, vol. 9, 1902, pp. 212–213.

[b] Salisbury, R. D., Glacial work in western mountains in 1901: Jour. Geol., vol. 9, 1901, pp. 718–731.

[c] Willis, Bailey, Changes in river courses in Washington Territory due to glaciation: Bull. U. S. Geol. Survey No. 40, 1887, pp. 7–8.

[d] Russell, I. C., Bull. U. S. Geol. Survey No. 108 1893, pp. 90–92.

and its subsequent work has been the removal of these sediments from its valley. New and lower flood plains have been formed at intervals during this restoration of the old channel, a fact which accounts to some extent for the irregularity of the lower benches.

All the terraces within 300 feet of the river level were formed since the disappearance of the greater part of the barrier and under nearly normal river conditions.

The upper terraces consist of only imperfectly stratified sands and silts. Coarse gravels are comparatively rare and no false bedding has been observed. The lower benches, on the other hand, are characterized by much false bedding. In many places they are composed of coarse gravels and sands and have all the characteristics of river deposits.

RELATION OF GOLD DEPOSITS TO TERRACES.

Where observed the placer gold along the Columbia is confined to the lower benches and river bars, a condition which may reasonably be expected if the sediments of the upper terraces are lake deposits, and those of the lower terraces have been worked over and concentrated by the river. Moreover, the later benches and the modern river bars are progressively richer in gold, since they are the product of repeated concentrations of the various upper terraces which have fallen into the river and been washed away.

The terraces on which deposits of placer gold occur are all within 200 feet of the level of the river. They are in the main covered with a sandy soil from a few inches to 12 feet or more thick, containing some disseminated gold, below which is a pay streak from 1 inch to 4 feet thick, consisting of sandy clay and gravel resting on a thin bed of clay. Below this pay streak there is generally barren sand, gravel, or in some places clay to the level of the river. It is reported that a second or a third lower pay streak occurs at a few places, but no attempts have been made to mine such deposits, and our investigations indicate that they invariably contain less gold than the upper placers. The pay streak is as a rule stained by oxide of iron and easily distinguished from the overlying slits by its color. The gold tenor varies from a fraction of a cent to a possible maximum of $1.50 per ton, the average being not more than 4 or 5 cents per cubic yard. These gold deposits were tested by carefully panning samples taken from prospect holes and such natural exposures as cut banks of streams and upturned tree roots. The colors of gold in each pan were counted, the number recorded, and specimens from the various localities weighed on an assayer's balance to determine their average value. To check these results 31 samples of pay dirt were collected and sent to the United States Geological Survey concentrating pavilion at Portland, Oreg., where they were tested by fire assay. In making the assays about

five times the ordinary amount was taken for fusion and quantitative determinations were made where, by ordinary methods, nothing but traces could have been reported. The colors of gold were found to range in value from less than 0.0005 to 0.02 cent, the average being about 0.002 cent. Nearly all of this is flour rather than flake gold and although very fine it is usually not difficult to save in panning. Some of the colors which appear to be larger, however, are thin flakes and scales that are very hard to separate from the black sand.

There is a noticeable difference in the size of the colors at various points along the river, some of the bars being characterized by very fine gold, and that of others being comparatively coarse. Generally the colors of any particular bar or pay streak are nearly uniform in size and appearance, but there are a few notable exceptions to this rule, some of the localities affording coarse flakes as well as uniformly fine flour gold, seeming to indicate a local source of supply for part of the gold.

ASSOCIATED MINERALS.

The gold is associated with black sand containing a large amount of magnetite and somewhat smaller amounts of ilmenite, zircon, garnet, and other heavy minerals. Platinum probably also occurs in small quantities, though its presence was not detected in the field.

An average sample of sand was run over the Wetherill separator at the concentrating pavilion and its mineral constituents were determined as follows:

Mineralogical composition of average sand from Columbia River terraces.

Magnetite	0.3
Ilmenite	.1
Garnet	.1
Zircon	.1
Quartz	39.4
Others	60
	100

One large color of gold and 16 to 20 small colors of platinum.

The amount of black sand in the pay streaks is much greater than in this sample, in some places reaching 3 or 4 per cent.

TYPICAL LOCALITIES.

Although there is probably some gold in the sands of the river throughout its length, the gold-bearing terraces on either side, which are called bars, are not continuous. Those adjacent to the right bank that were examined are Nespelem Bar, at the mouth of Nespelem River; Hell Gate Bar, a few miles above the Sanpoil; Peach Bar, opposite Peach post-office; Sixmile and Ninemile bars, 6 and 9 miles respectively above Spokane River; Wilmot Bar, opposite

Jerome post-office; Rogers Bar, a few miles below Hunter; Blue and Turtle Rapids bars, about 5 miles above Hunter; Stranger Creek Bar, opposite Gifford; and a bar about 6 miles above Daisy. In the Sanpoil Valley there are no indications that placer gold has ever been produced or exists in commercial amounts except on one or two of its tributaries. The more important of the deposits named above will be described in detail as follows:

COLUMBIA VALLEY.

Nespelem Bar is a terrace half a mile wide, 100 feet above the Columbia at the mouth of the Nespelem, which flows across the bar in a narrow canyon. Two miles above its mouth the Nespelem is incised in an upper terrace more than 1,000 feet above the Columbia, to which it descends in a series of falls caused by outcropping crystalline rocks. The lower terrace has a nearly level surface and where cut by the canyons presents the following section:

Section of lower terrace on Columbia River at mouth of the Nespelem.

	Feet.
Sandy loam	8–15
Gravel	½–1
Stratified clay, locally called soapstone	80

Although 320 acres of land situated here have been secured by patent for placer-mining purposes, gold was found at only one locality in a thin pay streak, consisting of iron-stained sandy clay resting on sand, somewhat above the general level and covering about 2 acres of ground. No gold was found by panning in any of the beds composing the foregoing section. Similar tests of the sands from the beds of gullies cutting through to the clay bed rock and of material from the bed of Nespelem River also gave negative results. It was estimated that there is no ground on this bar which can be expected to yield as much as 0.01 cent per cubic yard by placer-mining methods.

Hell Gate Bar, situated on the north side of Columbia River, between the mouth of the Sanpoil and Hell Gate Rapids, is a strip of land about 2 miles long and from 300 feet to half a mile wide. The placer gold is confined to a low bench, which is probably overflowed at times of extreme high water. Much of its surface is covered with river bowlders from a few inches to a foot in diameter, and the pay dirt is contained either in the crevices between these bowlders or in a well-defined pay streak consisting of iron-stained gravel from a few inches to a foot thick within 3 feet of the surface. There is little overburden and the gold-bearing layer is easily reached. The average value of this pay streak is estimated by panning to be 5 cents per cubic yard. The colors of gold are all fine, averaging

not more than 0.00125 cent in value. A sample of the richest material found was tested at the concentrating pavilion in Portland, Oreg., showing approximately the same result as to gold tenor. It was estimated that on this bar there is a deposit of pay dirt 6 inches thick, from 100 to 600 yards wide, and 2 miles long, which will average between 1 and 5 cents per cubic yard. Some of the richest of this ground was taken up by Chinese, who attempted to work it mechanically with water pumped from Columbia River, but their efforts were abandoned several years ago for the reason, as reported, that wages could not be obtained. The Columbia at Hell Gate Rapids is obstructed by a ledge of rocks that crosses from north to south. This ledge has been worn down by the river, but has probably always presented an obstruction to the current. The concentration of the gold below the rapids is probably due in part to this obstruction, an eddy being formed here in which the fine gold settled from the swiftly moving currents.

Between Hell Gate and the mouth of the Spokane there is comparatively little level land adjoining the river on the Colville Reservation. All of it is comprised in a low bench at the mouth of White Stone Creek, containing something over 300 acres, a similar bench opposite Creston Ferry, and a bench and bar opposite the town of Peach. The White Stone lands are entirely embraced in Indian ranches and were not examined for evidences of placer gold. A portion of the bench at Creston Ferry has been worked by placer miners, but the old workings are now abandoned and were not tested. Opposite Peach there is a bench about 300 feet above Columbia River which extends upstream to the mouth of the Spokane. A number of placer-mining claims have been located on this terrace, and it was examined critically. Where undermined by the river it presents the following section:

Section on Columbia River opposite Peach.

	Feet.
Light-colored sandy loam	12
Sand and gravel	1–2
Sandy clay, above which there is water seepage	6
Open cross-bedded gravel, containing many basalt pebbles one-fourth inch to 2 inches in diameter	200

No colors of gold could be obtained by panning from any part of this section, either from the sandy loam at the top or the gravel layer above the clay seam.

Between Peach and the mouth of Spokane River there is a large island in Columbia River that is overflowed at extreme high water. The upper end of this island was formerly worked by Chinese, their excavations reaching a depth of 3 or 4 feet. No mining is in progress there at the present time, and a part of the island is under cultivation.

From a point 3 miles above the mouth of the Spokane old Chinese excavations and ditches occur at short intervals for about 6 miles to the mouth of Ninemile Creek. None of these old workings extended more than 100 yards from the river.

Three miles above the Spokane is a bench about 20 feet above the river that contains an accumulation of large angular bowlders having the appearance of a moraine. It is probably the deposit mentioned by Salisbury as the terminal moraine of the Columbia River glacier.[a] It extends along the river about one-half mile. The pay streak, formerly worked by Chinese, occupies the spaces between these bowlders, which probably served as riffles to concentrate the fine gold. Some virgin ground found under a stump in the old workings yielded a fair result from panning, the colors being of two types, large thin flakes averaging 0.01 cent in value and the ordinary flour gold of the river averaging not over 0.002 cent in value. A sample tested by fusion at the concentrating pavilion gave $1.60 per ton in gold, but owing to the prevalence of bowlders not included in the sample this result should naturally be reduced about one-half.

At the mouth of Sixmile Creek, a mile above the point just mentioned, the glacial bowlders are no longer to be seen and a section of the terrace deposit was found to be about as follows:

Section on Columbia River at mouth of Sixmile Creek.

	Feet.
Silt and gravel, containing some clay	2
Gravel and clay	½
Coarse open-textured gravel, pebbles mostly from older rocks and 4 inches or less in diameter	20

The pay streak here is confined to the upper 2 feet of the section and was found by panning to have a value of 8 cents per cubic yard. The gold obtained includes some large thin flakes averaging 0.01 cent in value and much fine flour gold. A sample tested by fusion at the concentrating pavilion yielded only 4 cents per ton. There is a pay streak 2 feet thick here, extending back from the river possibly 800 or 900 feet, which will yield from 4 to 8 cents per cubic yard.

Two miles farther up the river, near the mouth of Ninemile Creek, there are something over 300 acres of land in two benches, one about 30 and the other 100 feet above Columbia River. The section on the lower bench is approximately as follows:

Section of lower bench on Columbia River near Ninemile Creek.

	Feet.
Sandy silt, from a few inches to	7
Iron-stained sand, gravel, and clay (pay streak)	1
Open-textured gravel	20

Old Chinese workings extend about 200 feet back and three-fourths of a mile along the river. The limit of the workings back from the

[a] Salisbury, R. D., Jour. Geol., vol. 9, 1901, p. 722.

river was evidently determined in some places by the thickness of the overburden and in others by the thinning out of the pay streak. The gold contains some large flakes worth 0.02 cent and much fine flour gold, bringing the average down to 0.0067 cent. The pay streak probably averaged a little over 40 cents to the cubic yard. A sample tested by fire assay at the concentrating pavilion gave 16 cents per ton.

The upper terrace, 100 feet above the river, presents a somewhat similar section, comprising from 1 to 3 feet of iron-stained gravel, sand, and clay, resting on more than 90 feet of cross-bedded gravel and sand. Panning tests showed that the upper layer carries a small fraction of a cent in flour gold per cubic yard, while the gravel and sand below show no trace of gold.

Wilmot Bar is about 6 miles farther up the river, opposite Jerome post-office. As at Sixmile Bar, there are two terraces here—one 20 feet, the other about 100 feet above the river. The lower terrace is situated just below a series of rock ledges forming an obstruction to the current somewhat similar to that at Hell Gate and the concentration of gold on the bar is probably due in part to this cause. On the lower terrace there is a surficial deposit from 1 to 5 feet thick that contains flour gold and rests on open-textured gravel and sand. Panning tests indicate a possible value of 10 to 14 cents per cubic yard on the lower bench and a small fraction of a cent per cubic yard on the upper one.

Rogers Bar, on the west bank of the Columbia 2 miles below the town of Hunter, contains approximately 1,500 acres of nearly level land that lies from 20 to 100 feet above high water and extends for 3 miles along the river. It includes three distinct benches—one 30, another 75, and a third 100 feet above the river. Near the middle of the bar two men are still working with rockers on the river bank, following the edge of the water as it falls. They report that the best pay is found on bars exposed only at low water. Half a mile below their workings there is a low gravel bar that is scarcely above the level of the river at ordinary stages; this was nearly all worked over by Chinese. A miner working here reported that under favorable conditions he could make as high as $3 per day. Near the lower end of Rogers Bar is a large island in the river known as Hog Island. The channel between it and the mainland is dry at low water and its bed has all been worked by Chinese.

The section of the deposit forming the lower terrace at Rogers Bar is as follows:

Section of lower terrace on Columbia River at Rogers Bar.

	Feet.
Sandy silt	2–8
Gravel and clay (pay streak)	$\frac{1}{6}$–1
Open-textured cross-bedded sand and gravel	20

The section in the next higher bench is similar except that the underlying gravel contains more sand and there is a greater thickness exposed. On the lower bench flour gold to the value of 1 to 50 cents per cubic yard was found in the pay streak, and a much smaller amount disseminated through the overburden. Tests by fusion at the concentrating plant gave somewhat higher values and would seem to indicate that there is a considerable amount of finer gold which could not be saved by ordinary panning. In some instances traces of platinum were reported by the assayer, but the amount was not determined. No gold was found on the uppermost terrace, which as noted lies 100 feet above the river. The bars below the level of ordinary high water carry values in gold somewhat higher than those of the terraces, the indicated value being more than 30 cents per cubic yard. The colors of gold at Rogers Bar have an average value of about 0.00125 cent and the samples contained at least one color worth 0.01 cent.

Blue Bar, situated on the right bank of Columbia River, about 4 miles above Hunter, consists of a terrace from 100 to 1,000 feet wide and 20 feet above the river. Opposite the bar in the river lies Blue Bar Island, with an area of about 100 acres. Mining was done by Chinese at the upper end of this island, as well as at the edge of the terrace, to which water was brought in a ditch from a small stream known as Stray Dog Creek. The section of the deposit making up the terrace at Blue Bar is approximately as follows:

Section on Columbia River at Blue Bar.

	Feet.
Sandy loam	$\frac{1}{2}$–7
Iron-stained gravel, containing some clay (pay streak)	$\frac{1}{6}$–$\frac{1}{2}$
Open-textured gravel and sand	15

Nearly all the gold is confined to the pay streak, though scattering colors can be found in the overburden. The results of panning this pay streak indicate values ranging from less than a cent to 6 cents per cubic yard. Samples tested by fusion at the concentrating pavilion yielded from 2 to 41 cents per ton.

Two miles above Blue Bar, near Turtle Rapids, a bench 60 feet above high water extends along the river for several miles. Old Chinese workings here expose a nearly barren layer of sandy silt several feet thick, resting on a pay streak a few inches thick, consisting of gravel and clay, below which is open-textured gravel and sand. These old workings indicate that the pay streak was followed back from the river bank until the overburden became too thick to permit further mining in that direction. Some of the original pay dirt was panned, indicating an approximate value of 30 cents per cubic yard, one pan containing upward of 300 fine colors of gold, the average value of which was 0.00143 cent.

At the upper end of these old Chinese workings an attempt was made last summer to hydraulic this deposit, a small stream of water under a 30-foot head being used. The pay streak was estimated from panning to contain about 9 cents per cubic yard. Two fusions were made of the sample sent to the concentrating pavilion, giving from 1 cent to 13 cents per ton. Half a mile above this point a pay streak 2 feet thick lies on the surface of the bench, with no overburden. It extends back from the river 300 feet to the foot of the escarpment from a higher bench. Panning here indicates that this pay streak has a placer value as high as 9.5 cents per cubic yard. Two fusions were made of the sample taken from this place, one showing no trace and the other 15.5 cents per ton.

Attempts at mining have been made on the lower terrace at intervals above this point for several miles, but the workings are now abandoned. Mining by hydraulicking was in progress on a bench at the mouth of Stranger Creek, which enters the Columbia opposite Gifford. The section exposed here is as follows:

Section on Columbia River at mouth of Stranger Creek.

	Feet.
Sandy soil	7
Pay dirt, consisting of clay and gravel	1–3
Loose open-textured gravel and sand	20

The pay streak was tested by panning at several places and is estimated to contain from 40 cents per cubic yard at the richest spot to 5½ cents at the poorest. The sandy silt above the pay streak carries a small amount of gold, which is concentrated with that from the pay streak in hydraulicking. Prospect holes at other places on this bench seem to indicate that the pay streak is not of very great extent. A sample cut from the top of the overburden across the pay streak at its thickest part, thus including pay streak and overburden, was tested by fusion at the concentrating pavilion and gave results varying from 14 to 32 cents per ton. This placer is located on the bank of the river just below a ledge of rock which must have always acted as an obstruction to the current, and the rich deposit here bears the same relation to this obstruction as do the deposits at Hell Gate and Wilmot Bar to similar ledges.

For several miles above the Stranger Creek placer a terrace at the same level that extends back from the river a distance of 800 or 900 feet has been located for placer-mining purposes. The sections exposed in the river bank and in prospect holes indicate a deposit of gravelly soil about 2 feet thick, resting on an iron-stained pay streak, below which there is open-textured gravel. Panning tests of these deposits indicate a possible value of a fraction of a cent per cubic yard, to a depth of 2½ feet, but samples tested by fusion at the concentrating pavilion showed no trace of gold. Back of the lower terrace there

is a higher one about 300 feet above the river, containing 300 or 400 acres of land that has also been included in placer claims. These lands, as far as could be ascertained, have a light sandy soil to a depth of 1 or 2 feet, underlain by tough clay to an unknown depth. No traces of gold could be found in either the surface soil or the clay.

Benches lying 20 to 30 feet above the river level and similar to those which have been described extend along the left bank from this point nearly to Kettle Falls. One of these, 2 miles above Daisy, presents the following section in the cut bank of the river:

Section on Columbia River 2 miles above Daisy.

	Feet.
Soil	1
Iron-stained pay streak	$\frac{1}{2}$
Open-textured gravel and sand	18

Fragments of shells of river mollusks were found in the silt just below the pay streak. A sample from the pay streak was panned, showing a value of 2 or 3 cents to the cubic yard, but the assays made at the concentrating pavilion showed only a trace of gold.

A low bar in the river several miles above Daisy, formerly known as China Bar and reported to have been worked out by the Chinese, was also tested and the upper layer of sand and gravel yielded about the same result—2 or 3 cents to the cubic yard.

SANPOIL VALLEY.

The Sanpoil Valley is disproportionately large for the stream which it contains. Its walls are terraced to almost the same elevations as those of the Columbia Valley and it was probably occupied by an arm of the same lake as filled the Columbia. It also resembles the Columbia in that the lower terraces and benches are more irregular than the upper ones. Although colors of gold were found at intervals along this river they are not as uniformly distributed as along the Columbia and are not concentrated in pay streaks to the same extent. A great many placer claims have been located near the mouth of West Fork, in the vicinity of Alkire post-office. Tests with the gold pan indicated a value of about 4 cents per cubic yard in one or two small spots, outside of which colors of gold were very rarely found. These colors are rougher than those along the Columbia and average 0.0055 cent in value. A sample representing thirteen prospect holes, all of which were well located to find placer gold if present, was tested by fusion at the concentrating pavilion and showed no trace of gold. About 3 miles above its mouth West Fork of the Sanpoil receives a tributary called Gold Creek, and several miles up the latter Strawberry Creek enters. Reports of miners indicate fair prospects of gold on each of these latter streams, and an imperfect examination of them confirms the reports. The deposits along Strawberry Creek are said to be of the normal creek-placer type. They are confined to the bed and the imme-

diate flood plain of the stream, and the gold is of local origin. Below Alkire the sands of the Sanpoil Valley were tested at a number of places, almost invariably with negative results, though a few colors of gold were obtained near Keller. No deposits of gold-bearing gravel that will justify the expectation of successful development occur along Sanpoil River at any point except those noted on West Fork.

ORIGIN OF THE GOLD.

The ultimate source of the Columbia River gold is to be found in the areas of crystalline and metamorphic rocks to the north and east, which are known to contain gold-bearing quartz veins, as well as other ore bodies of various kinds containing gold. Millions of tons of such rocks were washed away in the formation of the river valley, and the deposits with which the valley was filled during the glacial period represent many millions more, the gold content of which has been concentrated in river bars. Much of this gold has doubtless been carried many miles, but that some of it is of comparatively local origin is indicated by the coarse flake gold found on some of the bars. Somewhat coarser and rougher colors of gold were obtained from the bed of a small creek several miles from the Columbia. It is probable that there are many such tributary streams in which colors of gold can be found which have added small amounts to the gold deposits of the river.

METHODS OF MINING.

The mining and collecting of finely divided gold like that along the Columbia is inevitably more difficult and requires greater care and skill than ordinary placer mining. The appliances which have been used are rather simple forms of rocker or sluice box equipped with blanket, carpet, or burlap riffles. Neither quicksilver nor copper plates are used in the boxes. In sluicing, the material is invariably passed over some form of grizzly which screens out the finer part and drops it to an undercurrent or spreads it over tables where the gold is collected. The Chinese probably ground sluiced before shoveling the pay dirt into the boxes. In two places where white men were mining last summer the whole deposit above the pay streak was hydraulicked and washed into the sluice with water under a small head from a canvas hose. One of the principal difficulties in mining this gold is encountered at the clean up. The gold is associated with such great quantities of black sand that it is almost impossible to separate it. The usual method of collecting the gold with quicksilver is laborious and expensive, often fails to extract much of the gold, and utterly fails to collect platinum if it is present. Experiments made at the concentrating pavilion at Portland have demonstrated that this separation can be accomplished economically by means of a Wilfley concentrator, but even by this means the expense of mining would probably not be greatly reduced.

CONCLUSIONS REGARDING COLUMBIA RIVER GOLD.

Nearly all the sands in the bed of Columbia River and on the adjoining terraces and benches throughout the region covered by this examination carry some fine gold. The relative amounts have not been accurately determined, though the statements of miners and prospectors indicate that the low bars in the river bed contain more gold than the deposits on the benches.

The average width of the river is about 1,500 feet, and it is probable that a considerable part of its bed from one side to the other is covered by sands and gravels containing some gold. The gold-bearing terraces are not continuous on either side, being absent for long stretches, and it may be safely estimated that if distributed so as to be continuous they would make a strip of land not exceeding 300 feet on each side of the river.

Many of the richer spots were discovered and worked out by Chinese, and there is no record of the amount of gold they obtained. Moreover, the observations described in this report were not sufficient to justify a close estimate of the amount of gold remaining. It would seem a liberal estimate, however, to put the average width of the gold-bearing areas, including the river bed and benches, at 2,400 feet, the thickness of the gold-bearing deposit at 6 feet, and the amount of placer gold originally contained within such limits at 1 cent per cubic yard. On these terms the total amount of gold contained in the river bed and adjacent benches did not exceed $28,000 per linear mile, and the total amount in the 90 miles between Kettle Falls and Nespelem did not exceed $2,500,000.

This gold is not uniformly distributed, but in very small areas is concentrated enough to justify mining, especially where rich deposits occur in the bed of the Columbia, since the comparatively cheap process of dredging is here available. The bench lands, however, are not adapted to any relatively inexpensive process of mining. Hydraulicking on a large scale is ruled out by the absence of bed rock and the scarcity of water at sufficient elevation; dredging, by the height of these deposits above the river and the impossibility of floating the machinery over them. Moreover, the possible profits from mining the bench lands would undoubtedly be less than the value of these lands for agricultural purposes.

GOLD DEVELOPMENTS IN CENTRAL UINTA COUNTY, WYO., AND AT OTHER POINTS ON SNAKE RIVER.

By Alfred R. Schultz.

INTRODUCTION.

The present paper comprises a brief preliminary statement of some of the results obtained from surveys made by E. E. Smith, B. A. Iverson, H. C. Schleuter, and the writer during the summer of 1906 in Tps. 23 to 39 N., Rs. 113 to 117 W., inclusive, Uinta County, Wyo.

The examination of this region was made primarily for the purpose of determining the locality of the various coal and oil beds that occur in Uinta County and to trace northward the coal formations mapped by A. C. Veatch and the writer in southern Uinta County during the summer of 1905. In carrying out this plan the surveys were carefully tied to the land corners, and geologic and sketch topographic maps were prepared on a scale of 2 inches to the mile, with a contour interval of 100 feet. These separate field sheets, covering an area a little larger than that included in the above-mentioned townships and ranges, are now being compiled into a single base map, on a scale of 1 inch to the mile, which will show all the streams, land corners, houses, fences, roads, and trails found in this examination and will be used as a base for the several maps that will accompany the complete report now in preparation. These maps will show the areal and structural geology, the location and depth of the coal beds, the location of the oil-bearing shales, the occurrence of iron and gold, and the regions where they may be found. It is the purpose in this preliminary report to give a short description of the occurrence of gold in central Uinta County and point out to what extent development has been carried. The detailed report on this area, to which the reader is referred for further information, will probably be ready for distribution during the spring of 1908.

SURFACE FEATURES.

This area has an elevation ranging from 5,700 feet on Snake River to 11,500 feet on the crest of the mountain ranges. In the vicinity of

Sheep Creek, a tributary to John Days River, where the most rugged topography was encountered, there is a change in the elevation of 3,000 feet in less than half a mile. The area is traversed from west of north to east of south by two parallel mountain ranges—Salt River Range and Wyoming Range—and is bounded on the northeast by the Gros Ventre Mountains, which extend in an east-southeast and west-northwest direction. Near the south end of the area the Salt River and Wyoming ranges become lower, passing into Absaroka Ridge and Meridian Fold, respectively, and they finally lose their topographic importance south of the area, where the rocks of which they are composed are deeply buried by Tertiary deposits. There are numerous minor ridges and folds, in general more or less parallel to the main ridges, the most important being the Hoback Range, which connects the Wyoming Range and the Gros Ventre Mountains. To the east of the Wyoming Range is the great plain-like basin of Green River, whose mean elevation is about 7,500 feet. The entire area, except a narrow strip along the eastern margin, is a rugged succession of mountain peaks and ridges cut by numerous gorges and canyons whose walls often are in places nearly perpendicular. Many of the hills, valleys, and slopes are well timbered with pine, fir, and spruce.

The drainage belongs to three great systems—Snake River, whose waters flow into the Pacific; Green River, whose waters flow into the Gulf of California; and Bear River, whose waters enter the Great Basin. The greater part of the drainage area is almost equally divided between Snake and Green rivers, with a margin in favor of Snake River, only a small area in the southwestern portion being drained by the tributaries of Bear River.

STRATIGRAPHY.

The survey of last summer was carried on with special reference to coal, nearly all of the work being restricted to the coal-bearing formations. Some time was devoted to the formations contiguous to the coal-bearing rocks, and sufficient information regarding their age was obtained to correlate them with similar beds in other parts of the country. The fossils collected were studied by Dr. T. W. Stanton and indicate that the formations studied and mapped in the field (Pl. I) are of Jurassic age and form the upper portion of the Jurassic in this area.[a]

[a] For the geologic time values of the rocks other than those mapped in Pl. I see Veatch, A. C., Coal and oil in southern Uinta County, Wyo.: Bull. U. S. Geol. Survey No. 285, 1906, pp. 332–334; or the report by th writer on coal in central Uinta County, Wyo., now in preparation.

STRUCTURE.

The main disturbance in this area occurred near the close of the Cretaceous period, during the interval marked by the unconformity between the lower Laramie and Evanston[a] formations. A second and minor disturbance occurred after the deposition of the Evanston beds. The movement during this disturbance was for the most part along several of the old lines of weakness, faulting and tilting the younger beds so that they dip in some places from 40° to 50° and in an opposite direction to the older underlying beds. A third disturbance may have occurred between the deposition of Jurassic and the Bear River. There are some evidences indicating that the lower Cretaceous is entirely wanting in this area, but this has not been positively proved. There was, however, at this time no great disturbance associated with folding and faulting, for throughout the area the Bear River formation is apparently conformable upon the known Jurassic beds.

The principal structural features of this region are parallel to each other and have a north-south trend with a slight westward deflection, which increases toward the north. These are the direct northward continuation of the faults and folds observed in the northern portion of the area mapped in southern Uinta County during the summer of 1905. The important structural features at the south end of the area here considered, named in order from east to west, are (1) a rather regular anticline, with two or more secondary folds the Meridian anticline; (2) a rather regular syncline, in places slightly overturned—the Lazeart syncline; (3) a large and persistent faulted anticline, with a downthrow to the east and a displacement of 14,000 to 15,000 feet; and (4) a broad syncline—the Fossil syncline—which lies for the most part west of this area. To the north the structural conditions become more complicated. Several new folds and faults occur, and the entire region is more disturbed, giving rise to the Hoback, Wyoming, and Salt River ranges. The important structural features at the north end of the area, named in order from east to west, are (1) a rather irregular, complex anticlinorium which gives rise to the Hoback Range and passes toward the south into a regular anticline; (2) a synclinorium, the south end of which is a monosyncline, with beds dipping from 25° to 45° W.; (3) a faulted anticline, with a downthrow to the east and a displacement of about 15,000 feet; (4) the northward continuation of the Lazeart syncline, which develops a secondary fold in the vicinity of Snake River; (5) the northward con-

[a] Evanston as here used is the same as the Evanston formation in southwestern Uinta County. (See contributions to Economic Geology, 1905: Bull. U. S. Geol. Survey No. 285, 1906, pp. 332, 335.) C. A. White (Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1879, pp. 240–241) used the name "Evanston coal series" in referring to the coal-bearing beds of Almy below the Wasatch and above the Bear River. Lesquereux (Sixth Ann. Rept. Geol. Survey Terr., 1873, p. 409) used the term "Evanston deposits."

tinuation of the Absaroka fault, which here lies along the east base of the Salt River Range. The displacement along this fault is about the same as in the south end of this area. The Salt River Range has been uplifted and its component rocks thrown into the sharpest folds. As most of the range lies west of this area, no detailed sections were made across it, but very probably the same type of structure exists here as in the Hoback Range. The faulted anticline (3) gives rise to the Wyoming Range, and the fault extends approximately along the eastern base of the range in much the same manner as the Absaroka fault along the Salt River Range. These two faults are connected by a cross fault in which the downthrow is on the south, with a displacement of about 5,000 feet. Near the south end of the Wyoming Range two or more secondary folds are developed.

MINING DEVELOPMENTS.

GOLD IN THE ROCKS.

The gold that has thus far been reported lies in the northern third of the area above described. The reported gold on the east side of the Wyoming Range occurs in sedimentary rocks of Jurassic age. The only prospecting that has been done is in the vicinity of Horse Creek, in T. 34 N., R. 114 and 115 W. Numerous claims have been staked out along this creek, but thus far practically no development work has been carried on. A few shallow pits have been opened on both sides of the creek. Some of these pits were visited by E. E. Smith and the writer last summer, but no indications of gold were visible. It is reported locally by persons who are interested in the claims that several assays of the rock on Horse Creek show high values in gold and silver. Among the best was a sample taken from the ledge on Wesley Vickery's claim, where the rock is said to assay as high as $66 per ton in gold and a maximum of about $18 per ton in silver. This claim was not visited nor any of the rock samples seen by members of this party while on Horse Creek, but the sample sent by Mr. Vickery from his 40-foot tunnel looks promising, and if much such came from this vicinity it would certainly justify further development. The Jurassic rocks here consist of bluish-gray shales and limestones, with some gray and yellow sandstone interbedded with dark-gray shales. They lie on the west side of the anticlinal fold and the beds dip toward the west at angles of 30° to 45°. On the north side of Horse Creek the strike turns abruptly and continues N. 40° W. approximately along the trend of the stream which here follows the outcrop of the Benton shale. In this locality the Jurassic beds are slightly brecciated and contain numerous small seams of calcite. Some of the rock shows considerable iron pyrite, and in many places iron stains are associated with the calcite cavities. The claims are by no means restricted to

the Jurassic outcrop, but cover the Bear River and Benton shale outcrop as well. In neither of these sedimentary beds was there any evidence of gold deposits. In several localities, however (as reported), fine gold particles or flakes have been found in the Benton shale. Wherever found, the flakes are disseminated through the shale and occur in very small quantities. It is said that two assays have been made of these shales and that traces of gold were found in both samples.

PLACER DEPOSITS.

OCCURRENCE AND CHARACTERISTICS.

Gold was observed at various points on Snake River and its tributaries. It occurs either in the gravels forming the terraces along the streams or in the deposits of bowlders, gravel, and sand filling the channels or forming the beds of the streams.

Interesting examples of terrace formation are seen on both sides of Snake and Hoback rivers at points where the valley expansions permit their preservation. At several places along Snake River above the canyon the terrace declivity shows a thickness of 10 to 15 feet of horizontal stratified pebbles and bowlders at elevations ranging from 50 to 100 feet above the river bed, and some of the highest terraces are as much as 200 feet above the river. The terraces slope gently toward the center of the valley, and their slopes are strewn with water-worn rock fragments similar to the material found in the river bed. The material consists chiefly of quartz, with some granites, schists, shales, slate, and sandstones, and here and there some volcanic material, which no doubt is derived from the upper Snake in the vicinity of the Yellowstone National Park. Snake River, between the canyon and the mouth of Hoback River, occupies in many places a wide shoal bed and in autumn exposes extensive bars of shingle and cobblestone, among which the river winds in several channels. Many of the terraces along Hoback River, below the canyon, extend back one-quarter to one-half mile from the present river channel, whose bed is paved with water-worn pebbles similar to the material found in the Snake River channel, the granites and schists coming from the Gros Ventre Mountains several miles to the northeast. Near the lower end of Hoback River, where the stream cuts across two anticlines of low dip and the eroded sandstones and shales produce ripples in the stream, several flakes or scales of gold were found in the sands accumulated near the water's edge. Whether these gold flakes occur in the gravels farther up Fall River above the canyon and along its tributaries heading in the Gros Ventre Mountains was not determined. Numerous small streams that emerge from the mountains can be utilized in sluicing operations or for generating power to run a concentrating plant.

That these upper Snake River gravels contain gold has been known for some time, and as early as 1862 prospectors were trying to extract the shining colors or gold flakes from the coarse gravels and fine sand along the stream. Some of the first workings on the Snake above the Grand Canyon were in Jackson Hole, north of Gros Ventre River. These early discoveries are described by Frank H. Bradley,[a] in his report on the Snake River expedition in 1872, as follows:

> A considerable excitement was stirred up, a few years since, by reported discoveries of placer gold in large quantities on the upper Snake, and many prospectors visited this region. A small hydraulic operation was undertaken near this point; but the gold was too fine and in too small quantities to pay, and the whole region was entirely abandoned after a few months. The coarse gold, found on the lower part of the Snake, appears to have entered the river below the canyon, which is still to the southward of us.

In 1878 Orestes St. John[b] found on the terraced interval along Snake River in the vicinity of Bailey Creek indications of old placer workings that had been opened in 1870 by a party of miners associated with Jeff Stantiford. The enterprise was, however, interfered with by the Indians and organized mining operations were discontinued. In recent years considerable prospecting has been done along Snake and Hoback rivers, but very little real development work has been carried on. Claims have been located and staked out on the gravel terraces along the greater portion of Snake River and along Hoback River below its canyon, but only enough work has been done to hold the claims.

The placer-gold deposits along Snake River may be classed as stream placers and bench placers. The stream placers consist of the deposits of bowlders, gravels, and sand that form bars, banks, fills, and shoals in or adjacent to the streams, filling the channels and forming the stream beds. Many of the bars, banks, and fills are only temporary and vary more or less during every heavy storm. The bench placers are located in the old stream deposits, which are at present represented by the terrace remnants that mark the former level of the stream at a considerable elevation above the present river bed. None of the stream-placer deposits within the area are at present worked and only in two localities are the bench placers mined systematically. These are on Andrew J. Davis's claim on the east bank of the river, north of the mouth of Bailey Creek, and on Hoffer & Rosencrans's claim at Pine Bar, on the south side of Snake River at the mouth of Pine Creek, 1½ miles below the mouth of Bailey Creek. (See map, Pl. I.)

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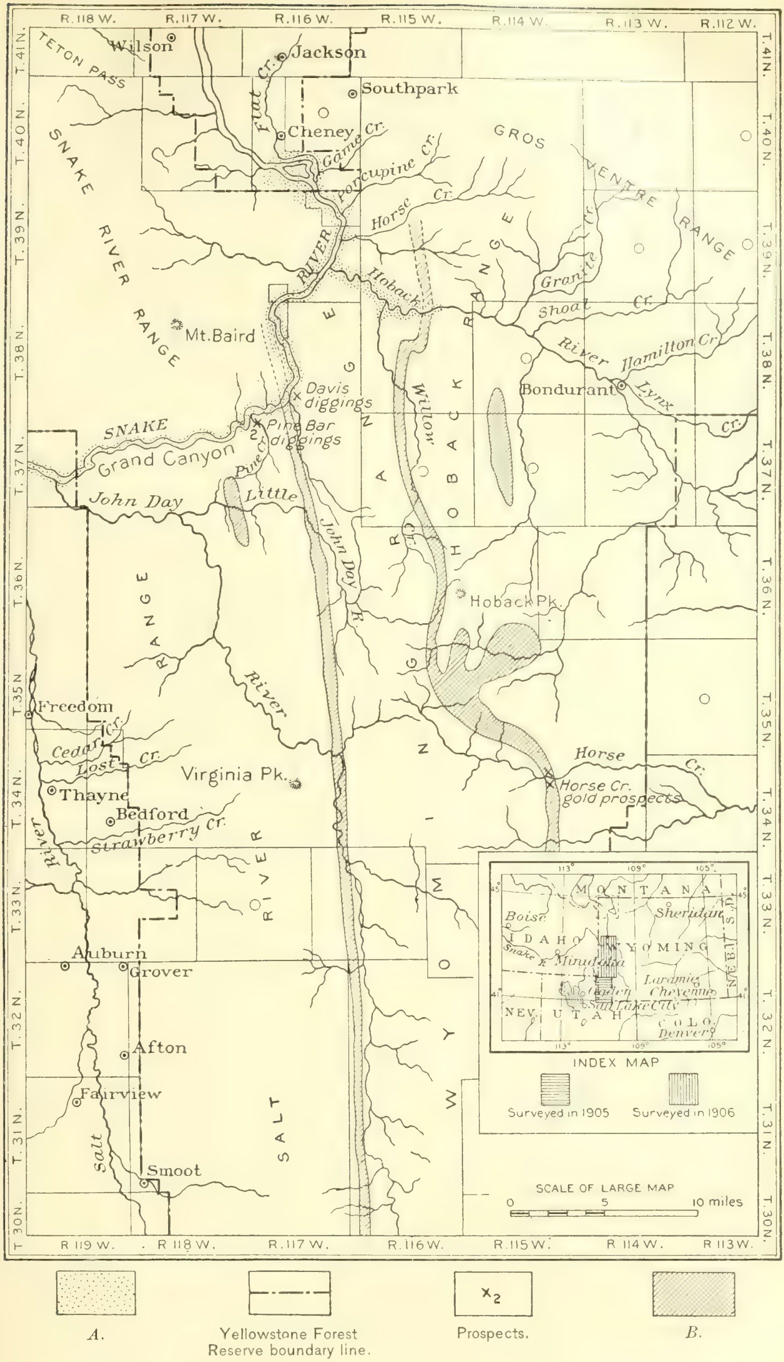
[a] Sixth Ann. Rept. U. S. Geol. Survey Terr., 1873, p. 266.

[b] Twelfth Ann. Rept. U. S. Geol. and Geog. Survey Terr., pt. 1, 1883, p. 196.



MAP SHOWING LOCATION OF SNAKE RIVER GOLD PLACERS IN A PORTION OF UINTA COUNTY, WYO.

A, Gravels known to be gold bearing. Some auriferous gravels extend farther up Snake River than here shown, but their distribution north of T. 39 N. is unknown. Similar gravels extend farther up Hoback River and its northern tributaries, but they are not known to be auriferous. *B*, Jurassic rock similar to the beds on Hoise Creek, in T. 34 N., Rs. 114 and 115 W., in which gold was reported to have been found.

DAVIS DIGGINGS.

The placer workings on the Davis claim are on a low terrace along the east side of Snake River, extending from the mouth of Bailey Creek about half a mile to the north. They are in the vicinity of those opened by Stantiford in 1870. There are two distinct terraces here, and Mr. Davis is at present working parts of both. The fine flour or flake gold of a high degree of fineness occurs all through the gravel, but is much more abundant in some streaks than in others. One of the main pay streaks near the Snake River channel is from 4 to 6 inches thick and is overlain by 4 to 6 feet of gravel that contains much lower values in gold and is in turn overlain by a nearly barren gravel bed 4 to 5 feet thick that extends to the surface. The rich pay streak, from 8 to 10 feet below the surface, makes it profitable to work the entire bank. On working back into the bank away from the river, these seams are found to rise and a new pay streak about 6 feet thick and richer than the other one is encountered. The new pay streak drops slightly farther east and probably represents the deposits of an older channel of Snake River. The different placer mines and even parts of the same terrace vary considerably in the character of the deposits and arrangement of their beds.

Water for hydraulicking is brought in a ditch from a point some distance up Bailey Creek and used to break down the gravels, wash out the gold and fine particles, and sluice through the flume. Sometimes the gravel is shoveled into the sluice boxes and in both methods the large bowlders are piled up in rows between the boxes so as to retain as much of the grade as possible and still work the lower pay streaks. The fine material drops through a series of steel-punched screens near the lower end of the sluice and is diverted at right angles through a distributing box onto a series of inclined tables about 4 feet wide and several feet long, covered with canvas or burlap, on which the gold and concentrates readily settle. About four-fifths of the gold and heavy concentrates are caught on the first few feet of the tables and are swept into a tray every few hours by diverting the pulp and turning on clear water. In order to catch the gold that may have escaped from the tables several boxes are placed in the path of the water between the tables and the river and the material collected in these boxes is run over the tables a second time. The concentrates and gold are stored until a sufficient batch is accumulated and are then placed in a small churn, or grinding pan, which is run by water power from the sluice box. Quicksilver and warm water are added to the concentrates and the machine set in motion. The gold amalgamates readily after a few hours of grinding and is then run into bars or sheets ready for the market. The gravels at these terraces, as shown by the workings for the last few years, run from 3 cents to $3

per cubic yard. Pay streaks that run $2 to $3 per cubic yard are very thin and rare. The average run of the gravels, all the pay streaks, and the comparatively barren gravels being considered together, is between 7 and 10 cents per cubic yard. Only one piece of coarse gold has thus far been found at this place. The nugget was said to be about half the size of a tenpenny nail.

During the last year several hundred dollars worth of gold was taken from this area. In Mineral Resources of the United States for 1905, page 341, the following statement is made under the heading of Uinta County, Wyo.: "A little placer gold is reported from Jackson Hole near the western boundary line of the State."

Four samples of black-sand concentrates were taken from Davis diggings and David T. Day in his report on these samples makes the following statement:

> These samples consist largely of magnetite, No. 1, apparently not much concentrated, containing 1 ounce of magnetite to 1½ ounces of the original material. They are all rich in gold but contain no platinum. The percentage of gold was not determined, but they will all range from $80 to $100 per ton and probably more. This gold could easily be extracted by means of shaking tables of the Pinder, Wilfley, Woodbury, or Deister type, but it is doubtful whether very much can be taken out by other means, certainly not by sluice boxes, as you have probably already found.

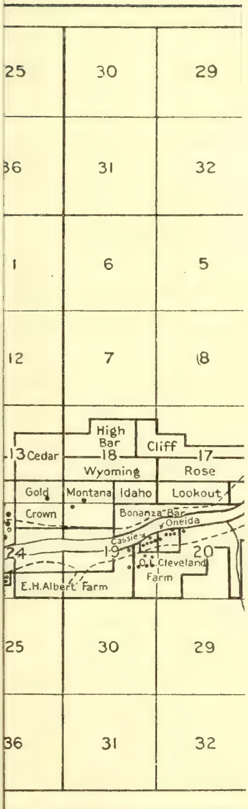
Doctor Day in his work on the investigation of black sands from placer mines[a] found that the effective operation of these concentrate tables is comparatively independent of the fineness of the gold. In many sands, gold as fine as 200 mesh is readily saved on the tables, frequently from 95 to 98 per cent of the total assayed value. A brief description of these tables and additional data on the black sands of the Pacific slope by David T. Day and R. H. Richards may be found in Mineral Resources of the United States for 1905, pp. 1175–1258.

PINE BAR DIGGINGS.

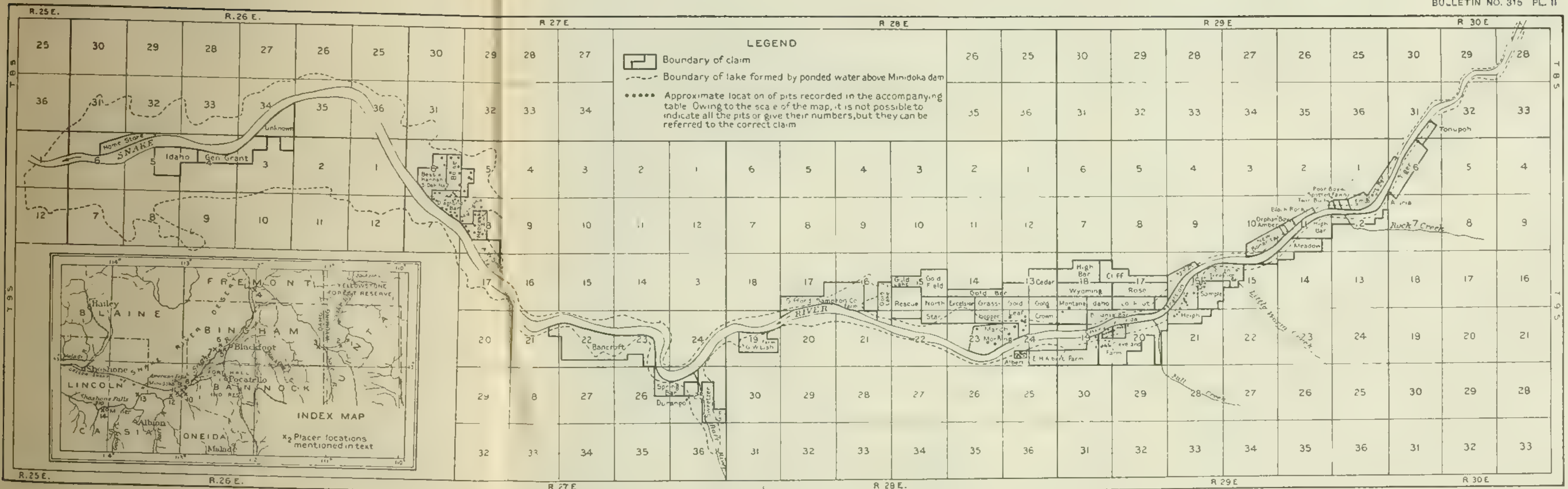
The terrace at the mouth of Pine Creek, on the south side of Snake River, has been worked during the last two years by Ivan L. Hoffer and L. M. Rosencrans. The methods employed are much the same as those above described for the Davis diggings. The water for hydraulicking is brought from a point some distance up Pine Creek in a ditch across the bench and used wherever it may be desired. The terrace or old bar at this point is 1 mile long and one-twelfth to one-eighth mile wide. The terrace for the most part is from 40 to 50 feet above the water level in Snake River.

Mr. Hoffer informed the writer that on this bar there is about 8 feet of overlying gravel that contains about 15 very fine colors per cubic foot, followed by 32 feet of gold-bearing gravel to water level without striking bed rock. So far only the upper 12 feet of this gravel, which is supposed to be better than that lower down, has been worked.

[a] Bull. No. 285, U. S. Geol. Survey, 1906, p. 164.



MINIDOKA, IDAHO.



MAP SHOWING LOCATION OF PLACER CLAIMS ALONG SNAKE RIVER IN THE VICINITY OF MINIDOKA, IDAHO.

Base taken from United States Reclamation Service index map of Minidoka project

The following figures furnished by Mr. Hoffer give the run of gold in colors for the first 12 feet of gravels as tested in two different places:

Colors of gold in upper gravel at Pine Bar diggings.

Depth in feet.	Colors per cubic foot.	
	A.	B.
1	7,200	6,300
2	23,400	3,600
3	8,100	16,200
4	106,200	11,700
5	8,100	11,700
6	22,500	4,500
7	3,600	5,400
8	17,100	900
	196,200	60,300

The tests were made on one-thirtieth cubic foot of gravel carefully measured and the results per cubic foot were obtained by multiplying these values by 30. About 1,000 to 1,200 colors make 1 cent value. Thus it will be observed that this 8 feet of gravel, both tests being averaged, prospects from 12 to 14 cents per cubic yard. Including the upper 8 feet, the value for 16-foot depth averages about 7 cents per cubic yard. Working to a depth of 20 feet or more should slightly raise this value. In a few places small streaks running up to $2 per cubic yard have been cut. Most of these streaks occur on top of the gold gravels immediately below the overlying 8 feet of comparatively barren material.

OTHER WORKINGS ALONG SNAKE RIVER.

Ivan L. Hoffer, who is fairly well acquainted with the placers of upper Snake River from Milner, Idaho, to the head of the river, states that the gold is much the same in character throughout the length of the stream, being a flour gold of a high degree of fineness. The placer miner usually recognizes two kinds of this gold—the free flakes and the coated. The different placers, however, show great variation in character of the deposits and distribution of the pay streaks. The locations of a number of placer workings along Snake River between the Davis diggings and Milner, Idaho, are indicated on the index map in Pl. II by numbers corresponding to those in the following notes, which were furnished by Mr. Hoffer:

1. Davis diggings, described above.
2. Pine Bar diggings, described above.
3. McCoy Creek. The bars of Snake River opposite the mouth of this creek have been worked some, but at present are idle. At the head of the creek, however, are large hydraulic placers that make a good clean up each year. It is claimed that they have enough ground to last a good many years at their present rate of working.
4. Market Lake. This neighborhood has been the scene of a number of small placer excitements in the past, but it is not known whether any work is being done here at present. Some dirt running as high as $7 per cubic yard has been taken out of the placers at this point but the rich pay streaks were very small in extent. Between the mouth of McCoy Creek and Market Lake the river is apparently barren.

5. Four miles below Blackfoot, Idaho, is the most extensive bar worked for placer mining on upper Snake River. It is owned by J. G. Walsh and is worked by leasers, two parties operating each year. A well-equipped dredge is usually run in the river at this point, but was not used last season.

6. During last season this placer was operated by Mr. Cole, but with what success has not been learned.

7. Not working at present. Owned by a Portland company that has considerable machinery and a small dredge on the ground.

8. I. L. Hoffer property. Assessment work only has been done at this point.

9. Franklin mine, one of the best known on Snake River, owned by Mary Franklin and Campbell & Stebbin. Reported yield, \$56,000. This claim consists of separate holdings.

10. Sorenson mine, owned by Julius Sorenson, of Neeley, Idaho, and worked by a company represented by Theodore Lindsley, of Neeley. This is the best mine on upper Snake River, having richer paid dirt than any other mine worked.

11. I. L. Hoffer claim, practically worked out. Some dirt running as high as \$100 per cubic yard was taken out at this point.

12. Worked by Dunn & Hand. The old style of placer workings will in time be crowded out here on account of the backwater from the Minidoka dam but dredging will no doubt be done.

13. A few miles below the Minidoka dam, E. A. Keats owns 160 acres on which he has done some rocker work for nine or ten years. Before beginning sluicing operations he is waiting for water from the Government ditch. A few miles below this point, opposite Peterson's ranch, is a bar on which some work is being done by Frank Eblett. This is the last of the workings above Milner, Idaho, as the backwater of the Milner dam has driven out those operating on Snake River between this place and Milner.

14. I. L. Hoffer claim; worked out.

Robert N. Bell, State inspector of mines, Boise, Idaho, states that in southern Idaho the counties bordering Snake River annually report to the United States assay office at Boise small shipments of gold derived from sluicing operations along the lower bars that border the stream for miles. These small operators are satisfied with \$2 to \$4 per day per man. During the summer they pick a favorable place along the first terrace that rises 10 to 20 feet above high-water mark and affords a dump. They then build what is locally called a "machine," consisting of about 30 feet of 3 to 4 foot sluice, floored with a steel-punched screen, and begin operations. (For methods see p. 77.) The water for sluicing is generally derived from some of the big irrigating canals or small streams in the mountains. This simple device intelligently handled will save a large percentage of the visible fine gold of the Snake River gravels, and is applicable as well to the large dredging operations. Some of these bars in the past have given this portion of the State a fair standing in the production of gold.

That part of Snake River which forms the boundary between Lincoln and Cassia counties, Idaho, was the scene several years ago of the most successful gold-dredging enterprise that has ever been conducted for the treatment of the extensive beds of fine gold-

bearing gravels for which Snake River is noted. The dredge was operated by the Sweetzer-Burroughs Dredging Company, of Minidoka, whose plant and methods were described in detail in the Engineering and Mining Journal, February 15, 1902 (reprinted in the report of the Idaho inspector of mines, for 1904). This plant was a suction dredge that ran several years and handled 3,000 cubic yards per day, saving probably about half of the gold content of the gravel raised from the low bars in and along the borders of the stream between high and low water marks. This company's operations commenced in the spring of 1894, when it practically had the choice of the stream. The results obtained, the best layers of gravel being skimmed to about 6 feet, averaged all through less than 10 cents per cubic yard. After several years of continuous operation, which resulted in one $10,000 dividend, the enterprise was abandoned, as the possible margin of profit was too small to warrant its continuance.

Robert N. Bell, in writing of the Snake River gravels in the vicinity of Minidoka, Idaho, makes the following statement: [a]

> I am skeptical about the invisible gold contents of these gravel deposits, except the coated gold, which is readily recognized. The Snake River fine gold is finer than any natural placer gold that I know of. It is high grade, but requires fully 1,000 to 1,500 colors to weigh 1 cent in value. Yet under a powerful microscope each color is an individual nugget showing abrasion marks. These particles are even coated, touched, or spotted with a crystalline white film, with some foreign substance that looks like silica under the glass, and this is what makes it necessary to polish it in the grinding pan before it will amalgamate freely. The size of the particles ranges within comparatively narrow limits, but there is no gradual shading from the smaller colors into imperceptible dust, and if the gravel contains any invisible gold that can not be recognized in an ordinary pan with the naked eye, it must be locked up in the particles of heavy concentrates.

The Government dam at Minidoka has raised the water over an adjacent high terrace that represents an old river bed and contains some of the best values in fine gold along Snake River. This terrace is known as Diamond Bar, and the shallow water now covering it affords a pond with sufficient water to float a chain-bucket or suction dredge, either one of which is adapted for treating this ground. A plan to dredge the terrace has lately received considerable attention from promoters, and already one company has organized and purchased several claims near the lower end of the backwater, with a view of installing a dredge and taking advantage of the favorable situation created by the Government irrigation enterprise.

In May and June, 1906, before the water was ponded above the dam, some prospecting on these gravels was done by the United States Geological Survey. The land examined by L. G. Gillette and W. L. Walker consisted of certain claims along Snake River in Idaho which would be submerged when the lake formed by the dam at Minidoka

[a] In a letter to the writer, January 12, 1907.

was full. The claim farthest upstream that was examined was the Golden Treasure, about 25 miles above the dam. The bulk of the work was done in the neighborhood of the old placers in order to determine the value of the ground that was formerly considered profitable. It was found that the values were very irregularly distributed and in but few places equal to the claims made by those interested in the land. The prospecting was accomplished by means of test pits, panning, and sampling, the samples taken being shipped to Portland, Oreg., where they were treated and assayed by the Survey in connection with the black-sand investigation. The information gained by the field tests and the assay of samples is not such as to place a specific valuation on any particular claim; but the results derived give the average values carried by the ground over which the pits were distributed. Comparative values for the various samples were determined in a preliminary way, merely for comparative purposes, on the ground by the count of the gold colors, and thus ready knowledge was had as to the location and extent of the mineral-bearing material. It was found that in general the values were concentrated in the bottom of the loam and the upper portion of the underlying gravels. The surface soil or sandy loam is common and ranges in thickness from 2 to 12 feet or more. The gold was everywhere of the finest flourlike particles, a large percentage of which would pass through a 150-mesh screen. The rocks are in general much smaller than a man's head, although in a few places rocks large enough to interfere with dredging or other mining operations were encountered.

After the sampling and assaying were completed the remainder of the "undersize" was mixed and run over a Wilfley concentrating table to determine the minerals present and to see whether or not the gold could be saved by that type of machine. The results obtained were excellent on both the loam and the gravel. A charge of 2,172 pounds of loam assaying 10 cents per ton was fed to the table, and a concentrate weighing 6 pounds 14 ounces was obtained, which assayed $33.28 per ton. The assay of the middlings (30 pounds) and of the tailings (5 assay tons being used in the large crucibles) showed only a trace of gold. The gravel gave equally satisfactory results; 3,850 pounds assaying 8 cents per ton yielded 8 pounds 10½ ounces of concentrates assaying $34.01 per ton. The middlings (52½ pounds) and tailings contained only a trace.

No other minerals of any commercial importance were found. No platinum or monazite was observed and only a trace of zircon. The richest sample contained only 4 pounds of magnetite per ton. These results indicate that the percussion type of machine can be used advantageously in separating the Snake River fine gold from the loam and gravels, especially after preliminary concentration in ordinary sluice boxes and shunting the concentrates onto the tables by

means of undercurrents. In the 25-mile stretch examined by Messrs. Gillette and Walker mining work was carried on only at the Sample placer claim, owned by W. H. Philbrick, who employed one stream in his ground-sluicing operations.

The following table shows the gold values in the placers along Snake River near the Minidoka dam. The location of the pits is shown on Pl. II (p. 78). The figures given under "Depth" indicate position with reference to the surface of the ground at which the samples were taken. "Percentage of oversize on 2 mm." indicates the portion too coarse to pass through a screen having openings 2 mm. (approximately one-twelfth of an inch) square. The "undersize" is that which passes through the screen. The value of the original gravel (oversize plus undersize) is given by the ton and by the yard, a yard being assumed at 1.3 tons. Under "Cumulative value" is given the average value of all material that would have to be moved in excavating to the depth indicated.

Gold values of Snake River placers in the vicinity of Minidoka dam, as determined in the black-sand investigation at Portland, Oreg.

Name of placer claim.	Owner.	Pit No.	Depth. From—		Depth. To—		Percentage of oversize on 2 millimeters.	Value of undersize.	Value of original gravel. Per ton.	Value of original gravel. Per cubic yard.	Cumulative value.
			Ft.	*in.*	*Ft.*	*in.*					
Diamond Bar....	Kinney...........	1	....		8	0	.0	Trace.	$0.00	$0.00	$0.00
			8	0	8	6	.7	$0.37	.37	.48	.03
			10	0	15	0	40.4	.12	.07	.09	.04
Do.....	.....do...........	2	5	4	9	4	15.6	.62	.52	.68	.29
			9	4	12	6	53.2	.04	.02	.03	.23
Do...........	.....do...........	3	6	0	8	0	48.0	.21	.11	.14	.03
Do...........	.....do...........	4	4	0	7	0	44.5	.33	.18	.23	.10
Do...........	.....do...........	5	4	0	6	0	71.6	.74	.21	.27	.09
			6	0	12	0	7.8	4.34	4.01	5.21	2.65
			12	0	14	0	76.9	.12	.03	04	2.31
Do...........	.....do...........	6	5	0	7	0	72.0	.50	.14	.18	.05
			7	0	11	0	63.1	None.	.00	.00	.03
Do...........	.....do...........	7	5	0	10	0	47.8	.41	.21	.27	.14
Do...........	.....do...........	8	....		3	10	10.2	None.	.00	.00	.00
			3	10	7	0	55.0	.08	.04	.05	.02
			7	0	8	6	....	.00	.00	.00	.00
Do...........	.....do...........	9	....		3	0	22.6	.33	.26	.34	.34
			3	0	4	6	73.2	.29	.08	.10	.26
			4	6	10	0	41.0	.21	.12	.16	.21
Do...........	.....do...........	10	2	0	3	0	14.1	.41	.35	.46	.15
			3	0	5	0	70.8	.99	.29	.38	.24
			5	0	9	6	9.0	.41	.37	.48	.35
Do...........	.....do...........	11	3	0	4	0	52.7	.37	.18	.23	.06
Do...........	.....do...........	12	3	8	4	6	31.9	.37	.25	.33	.06
			4	6	6	10	70.0	.79	.24	.31	.14
Do...........	.....do...........	13	3	6	5	0	63.8	.91	.33	.43	.13
			5	0	7	0	55.1	.08	.04	.05	.11
Do...........	.....do...........	14	6	0	2	6	33.1	.12	.08	.10	.08
			2	6	4	0	66.0	.50	.17	.22	.14
			4	0	7	0	....	....	....	....	.08
			7	0	8	6	6.8	None.	.00	.00	.06
			8	6	9	6	70.5	.04	.01	.01	.05
Do...........	.....do...........	15	1	6	3	0	32.9	.33	.22	.29	.15
			3	0	5	6	61.8	.33	.13	.17	.16
			5	6	5	9	54.7	.83	.38	.49	.17
Do...........	.....do...........	16	....		1	6	15.1	.16½	.13	.17	.17
			1	6	3	5	71.0	.62	.18	.23	.20
Do...........	.....do...........	17	....		1	8	24.7	.00	.00	.00	.00
			1	8	3	0	62.2	.25	.09	.12	.05
			3	0	7	0	56.3	.00	.00	.00	.02

Gold values of Snake River placers in the vicinity of Minidoka dam, as determined in the black-sand investigation at Portland, Oreg.—Continued.

Name of placer claim.	Owner.	Pit No.	Depth. From—		Depth. To—		Per-centage of over-size on 2 milli-meters.	Value of un-dersize.	Value of orig-inal gravel. Per ton.	Value of orig-inal gravel. Per cubic yard.	Cumu-lative value.
			Ft.	*in.*	*Ft.*	*in.*					
Diamond Bar	Kinney	18	......		1	6	17.9	$0.08	$0.07	$0.09	$0.00
			1	6	2	6	52.7	.21	.10	.13	.11
			2	6	8	0	46.0	None.	.00	.00	.03
Do	do	19	3	6	6	0	52.3	.17	.08	.10	.04
Do	do	20	......		6	0	.7	.04	.04	.05	.05
			6	0	11	6	68	.00	.00	.00	.03
Do	do	21	......		6	6	3.4	.04	.04	.05	.05
			6	6	7	10	59.0	.21	.09	12	.06
			7	10	8	10	54.5	.00	.00	.00	.05
Do	do	23	......		8	0	0	.12	.12	.16	.16
			8	0	10	0	41.9	.04	.02	.03	.14
Do	do	24	......		8	6	0	.04	.04	.05	.05
			8	6	10	0	59.4	.25	.10	.13	.06
Do	do	25	......		6	0	9.8	None.	.00	.00	.00
			6	0	7	0	54.8	.41	.19	.25	.03
Do	do	26	......		9	0	0	Trace.	.00	.00	.00
			9	0	9	6	59.2	1.28	.52	.68	.03
			9	6	11	6	63.2	.41	.15	.20	.06
Do	do	27	7	6	8	0	2.9	.08	.08	.10	.01
			8	0	9	0	49.5	Trace.	.00	.00	.01
Do	do	38	......		8	0	31.1	.08	.06	.08	.08
Do	do	40	......		11	0	8.5	.08	.07	.09	.09
Do	do	41	......		4	0	.7	.17	.17	.22	.22
			4	0	5	0	72.2	.87	.26	.34	.24
Do	do	42	......		6	6	0	.08	.08	.10	.10
			6	6	7	6	63.6	1.16	.42	.55	.16
Nebraska	R. Lilly & Co.	28	......		7	0	36.1	.41	.26	.34	.34
Do	do	29	......		7	0	11.5	None.	.00	.00	.00
Do	do	30	......		9	6	8.8	.29	.26	.34	.34
Do	do	31	......		7	0	2.6	.12	.12	.16	.16
			7	0	8	6	45.7	2.89	1.57	2.04	.49
Do	do	32	......		10	0	23.4	.29	.22	.29	.29
			10	0	10	6	23.4	.91	.70	.91	.32
Do	do	33	......		9	6	6.0	.17	.16	.21	.21
Do	do	34	......		7	0	36.4	.91	.58	.75	.75
Do	do	35	......		5	0	7.6	.04	.04	.05	.05
Do	do	36	......		4	0	15.8	.25	.21	.27	.27
			4	0	5	3	42.7	.04	.02	.03	.21
Do	do	37	......		9	6	2.6	.08	.08	.10	.10
Do	do	39	......		9	0	0	.04	.04	.05	.05
			9	0	10	3	46.9	.54	.29	.38	.09
Boise	do	43	4	8	7	8	57.7	1.07	.45	.59	.23
Do	do	44	......		9	0	......	None.	.00	.00	.00
			9	0	12	0	59.8	.12	.05	.07	.02
Do	do	45	......		11	0	0	.08	.08	.10	.10
Do	do	46	2	6	3	9	55.4	.12	.05	.07	.03
			3	9	8	0	38.9	.12	.07	.09	.06
Do	do	47	......		7	0	0	.12	.12	.16	.16
			7	0	14	0	54.3	.54	.25	.33	.24
Do	do	48	......		3	6	2.6	.17	.17	.22	.22
			3	6	5	6	58.3	.41	.17	.22	.22
			5	6	12	0	71.4	.04	.01	.01	.11
Do	do	49	......		10	0	22.8	None.	.00	.00	.00
Do	do	50	......		4	0	46.7	.08	.04	.05	.05
			4	0	11	0	35.1	.00	.00	.00	.02
Do	do	51	1	9	4	3	62.7	.04	.02	.03	.02
			4	3	9	0	36.0	.08	.05	.07	.05
Do	do	52	......		9	6	1.2	.08	.08	.10	.10
			9	6	11	6	38.8	.04	.02	.03	.09
Bessie Hannah	do	22	2	6	3	0	30.0	.58	.41	.53	.09
			3	0	6	0	50.5	......	......	......	......
Do	do	53	......		5	6	5.4	None.	.00	.00	.00
			5	6	10	0	37.8	.62	.39	.51	.23
Do	do	55	......		9	6	20.4	.12	.10	.13	.13
Do	do	56	......		5	0	1.3	.04	.04	.05	.05
			5	0	10	0	24.7	.12	.09	.12	.08
Goldleaf	Dunn, Hand & Hughes.	57	......		8	6	7.4	None.	.00	.00	.00
			8	6	13	0	40.6	None.	.00	.00	.00
Do	do	58	......		8	6	18.7	.62	.50	.65	.65
Do	do	59	......		8	0	27.8	None.	.00	.00	.00
Do	do	60	3	0	10	6	51.4	.08	.04	.05	.04
Do	do	61	1	0	8	0	18.4	.25	.20	.26	.23
Do	do	63	5	0	6	6	54.8	.12	.05	.07	.02
March Morning	Steele & Lockhart.	62	......		......		None	None	None.	None.	None.
Do	do	64	7	0	8	0	38.4	.50	.31	.40	.05

Gold values of Snake River placers in the vicinity of Minidoka dam, as determined in the black-sand investigation at Portland, Oreg.—Continued.

Name of placer claim.	Owner.	Pit No.	Depth. From— Ft.	Depth. From— in.	Depth. To— Ft.	Depth. To— in.	Percentage of oversize on 2 millimeters.	Value of undersize.	Value of original gravel. Per ton.	Value of original gravel. Per cubic yard.	Cumulative value.
March Morning..	Steele & Lockhart.	65			9	0	1.4	$0.00	$0.00	$0.00	$0.00
Do	....do	66	4	6	11	0	0	None.	None.	None.	.00
Do	....do	67		6	13	0	4.3	None.	None.	None.	.00
Do	....do	68	9	6	11	6	40.9	.12	.07	.09	.02
Do	....do	69			4	0	52.8	Trace.	.00	.00	.00
Grasshopper	Dunn, Hand & Hughes.	70	4	0	6	0	46.1	None.	.00	.00	.00
Do	....do	71			2	6	10.0	None.	.00	.00	.00
			2	6	6	0	59.1	.50	.20	.26	.15
Excelsior	....do	72			3	6	32.3	None.	.00	.00	.00
			3	6	9	0	4.2	.17	.16	.21	.13
Do	....do	73			2	0	9.5	.12	.11	.14	.13
			2	0	9	0	41.6	None.	.00	.00	.03
Albert	E. H. Albert	74	4	0	9	0	46.1	.08	.04	.05	.03
Do	....do	75	12	0	17	0	31.2	.70	.48	.62	.18
Do	....do	76	18	0	21	0	47.1	None.	.00	.00	.00
Do	....do	77	9	6	18	0	40.5	None.	.00	.00	.00
Do	....do	78	3	6	8	0	56.2	.33	.14	.18	.10
Do	....do	79	6	6	14	0	61.9	.08	.03	.04	.02
Do	....do	80	10	6	14	6	60.9	.08	.03	.04	.01
Do	....do	82	5	0	7	0	46.6	None.	.00	.00	.00
Albert (from east end).	....do	105	5	6	7	6	73.2	.58	.16	.21	.06
Do	....do	110	3	6	6	6	48.8	None.	.00	.00	.00
Gold Crown	Dunn, Hand & Hughes.	85	1	6	6	0	36.6	.17	.06	.08	.06
Montana P.	....do	87	2	0	6	6	37.6	.37	.23	.30	.21
Oneida Claim	O. L. Cleveland	89	3	0	9	0	75.4	.12	.03	.04	.05
Do	....do	90	9	6	14	0	69.6	.74	.22	.29	.10
			14	0	18	0	71.0	.04	.01	.01	.08
Do	....do	91	9	6	14	6	78.8	.48	.10	.13	.05
Do	....do	92	13	0	15	3	52.6	.58	.27	.35	.05
Do	....do	93	11	6	13	3	58.3	None.	.00	.00	.00
Do	....do	94	8	6	12	0	52.4	.52	.25	.32	.09
Cassia		95	8	0	9	0	66.9	.37	.12	.16	.02
			8	0	13	0	62.5	.12	.05	.07	.03
Do		96	6	6	10	6	62.5	.70	.26	.34	.13
Do		97	9	6	11	6	48.8	Trace.	.00	.00	.00
			11	6	15	0	32.1	.08	.05	.07	.02
Do		99	6	6	9	6	59.6	.54	.22	.29	.09
			9	6	13	6	48.0	.17	.09	.12	.10
Do		101	9	5	13	0	51.0	.17	.08	.10	.03
			13	0	17	0	7.2	.04	.04	.05	.03
Do		102	9	6	14	0	47.8	.29	.15	.20	.07
Do		103	5	6	12	0	1.3	.17	.17	.22	.12
			12	0	16	0	56.6	.04	.02	.03	.10
Do		104	8	6	12	0	44.4	.91	.51	.66	.19
Agricultural holdings.	O. L. Cleveland	106	4	6	9	0	58.5	None.	.00	.00	.00
Do	....do	107	4	6	7	0	67.0	None.	.00	.00	.00
			7	0	11	0	56.0	.17	.07	.09	.04
Do	....do	108	6	6	11	4	60.6	.25	.10	.13	.06
			11	4	12	4	26.8	None.	.00	.00	.05
Do	....do	109	3	6	6	0	25.0	None.	.00	.00	.00
			6	0	10	0	46.5	None.	.00	.00	.00
Do	....do	[a]105	5	6	7	6	73.2	.58	.16	.21	.06
Do	....do	[a]110	3	6	6	6	48.8	None	.00	.00	.00
Heigh	W. H. Philbrick	112	3	6	5	0	43.3	None.	.00	.00	.00
Do	....do	113	5	6	8	0	62.2	.17	.06	.08	.03
			8	0	12	6	66.3	.25	.08	.10	.05
Do	....do	114	6	6	8	6	61.7	.29	.11	.14	.03
			8	6	11	0	53.9	.17	.08	.10	.05
Do	....do	115	8	6	12	8	18.4	.79	.64	.83	.27
			12	8	16	0	73.9	.12	.03	.04	.22
Do	....do	116	11	6	20	0	50.0	.12	.06	.08	.03
Do	....do	117	4	0	8	0	36.7	.21	.13	.17	.08
Do	....do	118	3	0	13	0	61.6	.17	.07	.09	.06
Do	....do	119	13	6	17	0	48.9	.21	.11	.14	.03
			17	0	20	0	62.4	.04	.02	.03	.03
Do	....do	120	3	0	5	0	45.0	.17	.09	.12	.05
Do	....do	121	7	0	15	0	52.0	.08	.04	.05	.03
Do	....do	122	6	0	8	0	59.1	.04	.02	.03	.01
			8	0	17	0	52.3	.17	.08	.10	.06

[a] Nos. 105 and 110 are just over the line, on E. H. Albert's property.

Gold values of Snake River placers in the vicinity of Minidoka dam, as determined in the black-sand investigation at Portland, Oreg.—Continued.

Name of placer claim.	Owner.	Pit No.	Depth. From— Ft.	in.	To— Ft.	in.	Percentage of oversize on 2 millimeters.	Value of undersize.	Value of original gravel. Per ton.	Per cubic yard.	Cumulative value.
Height	W. H. Philbrick	123	11	6	15	6	51.0	$0.17	$0.08	$0.10	$0.03
Do	do	124	13	0	18	0	74.1	.04	.01	.01	.00
Do	do	125	2	6	7	0	72.1	.04	.01	.01	.02
			7	0	11	0	72.1	.04	.01	.01	.01
Do	do	126	4	0	5	0	48.5	.29	.15	.20	.04
			5	0	7	0	70.0	.54	.16	.21	.09
Do	do	127	16	0	20	0	64.5	.12	.04	.05	.01
Sample	do	128	3	6	9	0	50.0	.21	.11	.14	.09
Do	do	129	4	0	10	0	51.8	.06	.03	.04	.01
Do	do	130	4	6	9	0	43.8	.50	.28	.36	.18
Do	do	131	2	0	6	0	60.8	.25	.10	.13	.09
Do	do	132	5	6	11	6	52.1	.12	.06	.08	.04
Golden Treasure Bar.	do	133	2	6	7	0	69.6	.29	.09	.12	.08

Detailed records of each of the sections at the pits included in the foregoing table are given in the report by David T. Day on placer claims above the Minidoka dam which is now on file in the office of the Reclamation Service at Washington, D. C., and from which the above table is compiled.

The gravels along Snake River in the vicinity of Wapi, Idaho, have been worked by Dunn & Hand, all of their workings being on old high bars or terraces (part of which are now under water) along the present river channel. C. H. Hand states that the gold here is a very fine flake gold, and amalgamates readily. The gold is scattered through the gravel but is usually best at the top of the beds. It occurs in heaviest particles in the oldest bars. The pay streaks run from a few inches to 6 or 7 feet in depth, but in some places exceed 22 feet, at which depth the gold has run as high as 22 cents per cubic yard. Where bed rock lies at the shallow depths, say from 6 to 8 feet below the surface, the pay streak in some places rests on the bed rock. Occasionally two or more pay streaks are encountered, one on bed rock and the other higher in the gravels or near the top. It is, however, exceptional to find the pay streak on bed rock. The bars in this locality are very extensive, amounting to hundreds of acres. Actual clean-up, by sluicing some thousand of yards, shows a value of a little more than 20 cents per cubic yard for some million of yards. Gravels of much higher grade occur at some places in thin seams. For a short distance these may run as high as several dollars per cubic yard. The above averages are, however, for gravels worked from 12 to 15 feet in depth and include both the gravels and the surface soil. Besides the gold, the gravels for the above depths carry about three-fourths of 1 per cent of black sand and other heavy minerals.

Two or three enterprises now on foot at different points along the Snake River will test the problem of saving the possible by-products of the gravels in addition to the gold content. One of these is being undertaken at a point on the Oregon side of the river a short distance below Weiser, Idaho, and another at a point a short distance above American Falls, Idaho. The results of these efforts will be watched with much interest, for, if any margin of profit at all can be made in which platinum becomes an important factor in the output, it will be important to the country at large, as the business might be greatly extended, since there are billions of yards of these low-grade gold and platinum-bearing gravels along the banks of Snake River. The portion of Snake River below the Grand Canyon that flows through Bingham, Blaine, Oneida, Cassia, and Lincoln counties, Idaho, yielded in 1905 approximately 1,300 fine ounces of gold, valued at a little more than $26,000.

PLATINUM IN THE SNAKE RIVER AURIFEROUS GRAVELS.

The recent experiments of David T. Day, of the United States Geological Survey, at Portland, Oreg., on the heavy placer concentrates of the Pacific slope, to determine their value in other metals and minerals besides gold, included a number of samples of Snake River concentrates, nearly all of which yielded from a trace to an appreciable amount of platinum, but Doctor Day doubts whether many of the results were obtained from representative samples. The subject is interesting and well worthy of close and intelligent investigation. It may prove, however, that under the present state of the platinum market, the platinum values are too thinly scattered along this stream to be of much value unless they are combined with the concentrates and have largely passed unnoticed. The actual contents of magnetite and similar heavy residues in these gravel beds, as nearly as has been determined, is from one-fourth to one-third of 1 per cent of the gravel, and when their visible free-gold content is properly amalgamated out the residue will not assay over $5 in gold per ton.

During the past year Robert N. Bell, State mine inspector of Idaho, visited the point on Snake River from which the highest results in platinum were reported during the progress of the Portland fair. A sample taken at this point yielded platinum at the rate of eighteen one-hundredths of an ounce per ton and several hundred dollars in gold per ton. Mr. Bell learned that the sample was selected from the first burlap on one of the "machine" tables, with the fine gold left in, and probably represented a concentration of several thousand to one. A subsequent sample of clean black concentrates taken from below the grinding pan, after the free gold had been amalgamated out, was sent to Doctor Day and gave a result of $3 gold per ton and only a trace of platinum.

The gravel containing the gold and platinum is usually well worn and small, affording ideal conditions for dredging and with a large enough plant and intelligent handling may be made to pay. The possible margin of profit, however, working for the gold content alone, would be small and unattractive, unless associated values of gold or platinum not apparent to ordinary methods of saving can be recovered. That platinum in metallic form is associated with the gold in these gravel beds can not be questioned, for while it can rarely be seen in panning it invariably shows in cleaning amalgam. In the operation of the Sweetzer-Burroughs dredge near Minidoka, it was always observed at clean-up time, appearing as ashy gray metallic particles floating on the "quick" when the hard amalgam was thinned down with more "quick" for the purpose of separating foreign matter from the gold. A quarter of an ounce of clean platinum recovered in this manner is now in the possession of Lewis Sweetzer, of Rupert, Idaho. It is perfectly clean gray metal in scaly particles and about as fine as the fine gold.

SOURCE OF GOLD.

The source of the Snake River fine flour or flake gold is unknown. The fineness of the individual particles and the abrasion marks seen on some of the pieces suggest that they have been carried for some distance. From the evidence gathered within the area studied this season it seems likely that the gold was carried from regions lying farther north and northeast. It was probably derived from the older rocks of the Teton and Gros Ventre ranges or from the region of the later intrusives of the upper Snake Valley. The old bars and benches containing the gold were built up in much the same manner as those now forming in the river, and some of the gold particles have been worked over and over again by the river until they are finally mined in their present places.

The thickness and value of the pay streaks is no doubt dependent on the local conditions under which they were deposited. The gradient of the stream as well as the volume of the water, its turbidity, and the time during which it flowed in the same channel would affect the distribution, thickness, and richness of the pay streaks. Unlike other gold placers those of Snake River do not increase in gold values as bed rock is approached, for the gold is usually more plentiful in the gravel banks between present and former high and low watermarks than at the deeper horizons. By the completion of the Milner and Minidoka dams the flow of the stream has been absolutely stopped for several days at two points along its course within the past two years, and its bed rock has thus been laid bare for miles during periods in which its potholes and crevices were searched in vain for paying gold values.

SURVEY PUBLICATIONS ON GOLD AND SILVER.

The following list includes the more important publications by the United States Geological Survey on precious metals and mining districts. Certain mining camps, while principally copper producers, also produce smaller amounts of gold and silver. Publications on such districts will be found in the bibliographies for copper on pages 108 and 109 and for lead and zinc on page 128. For a list of the geologic folios in which gold and silver deposits are mapped and described, reference should be made to the table on pages 9 to 13 of the present bulletin:

Arnold, Ralph. Gold placers of the coast of Washington. In Bulletin No. 260, pp. 154–157. 1905.

Bain, H. F. Reported gold deposits of the Wichita Mountains [Okla.]. In Bulletin No. 225, pp. 120–122. 1904.

Ball, S. H. Geological reconnaissance in southwestern Nevada and eastern California. In Bulletin No. 285, pp. 53–73. 1906. Also Bulletin No. 308.

Barrell, Joseph. Geology of the Marysville mining district, Montana. Professional Paper No. 57. 1907.

Becker, G. F. Geology of the Comstock lode and the Washoe district; with atlas. Monograph III. 422 pp. 1882.

——— Gold fields of the southern Appalachians. In Sixteenth Ann. Rept., pt. 3, 251–331. 1895.

——— Witwatersrand banket, with notes on other gold-bearing pudding stones. In Eighteenth Ann. Rept., pt. 5, pp. 153–184. 1897.

——— Brief memorandum on the geology of the Philippine Islands. In Twentieth Ann. Rept., pt. 2, pp. 3–7. 1900.

Boutwell, J. M. Progress report on Park City mining district, Utah. In Bulletins No. 213, pp. 31–40; No. 225, pp. 141–150; No. 260, pp. 150–153.

Cross, Whitman. General geology of the Cripple Creek district, Colorado. In Sixteenth Ann. Rept., pt. 2, pp. 13–109. 1895.

——— Geology of Silver Cliff and the Rosita Hills, Colorado. In Seventeenth Ann. Rept., pt. 2, pp. 269–403. 1896.

Cross, Whitman, and Spencer, A. C. Geology of the Rico Mountains, Colorado. In Twenty-first Ann. Rept., pt. 2, pp. 15–165. 1900.

Curtis, J. S. Silver-lead deposits of Eureka, Nev. Monograph VII. 200 pp. 1884.

Diller, J. S. The Bohemia mining region of western Oregon, with notes on the Blue River mining region. In Twentieth Ann. Rept., pt. 3, pp. 7–36. 1900.

——— Mineral resources of the Indian Valley region, California. In Bulletin No. 260, pp. 45–49. 1905.

Eckel, E. C. Gold and pyrite deposits of the Dahlonega district, Georgia. In Bulletin No. 213, pp. 57–63. 1903.

ELDRIDGE, G. H. Reconnaissance in the Sushitna basin and adjacent territory in Alaska in 1898. In Twentieth Ann. Rept., pt. 7, pp. 1-29. 1900.

EMMONS, S. F. Geology and mining industry of Leadville, Colo.; with atlas. Monograph XII. 870 pp. 1886.

——— Progress of the precious-metal industry in the United States since 1880. In Mineral Resources U. S. for 1891, pp. 46-94. 1892.

——— Economic geology of the Mercur mining district, Utah. In Sixteenth Ann. Rept., pt. 2, pp. 349-369. 1895.

——— The mines of Custer County, Colo. In Seventeenth Ann. Rept., pt. 2, pp. 411-472. 1896.

EMMONS, W. H. The Neglected mine and near-by properties, Colorado. In Bulletin No. 260, pp. 121-127. 1905.

——— Ore deposits of Bear Creek, near Silverton. In Bulletin No. 285, pp. 25-27. 1906.

——— Notes on the Manhattan district [Nevada]. With Ransome and Garrey in Bulletin No. 303.

GALE, H. S. Hahns Peak gold field. In Bulletin No. 285, pp. 28-34. 1906.

GARREY, G. H. Notes on the Manhattan district [Nevada]. With Ransome and Emmons in Bulletin No. 303.

GRATON, L. C. Gold and tin deposits of the southern Appalachians; with notes on the Dahlonega mines by Waldemar Lindgren. Bulletin No. 293. 134 pp. 1906.

HAGUE, ARNOLD. Geology of the Eureka district, Nevada. Monograph XX. 419 pp. 1892.

HAHN, O. H. The smelting of argentiferous lead ores in the Far West. In Mineral Resources U. S. for 1882, pp. 324-345. 1883.

IRVING, J. D. Ore deposits of the northern Black Hills. In Bulletin No. 225, pp. 123-140. 1904.

——— Ore deposits of the Ouray district, Colorado. In Bulletin No. 260, pp. 50-77. 1905.

——— Ore deposits in the vicinity of Lake City, Colo. In Bulletin No. 260, pp. 78-84. 1905.

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——— The gold-quartz veins of Nevada City and Grass Valley districts, California. In Seventeenth Ann. Rept., pt. 2., pp. 1-262. 1896.

——— The mining districts of the Idaho basin and the Boise Ridge, Idaho. In Eighteenth Ann. Rept., pt. 3, pp. 625-736. 1898.

——— The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho. In Twentieth Ann. Rept., pt. 3, pp. 75-256. 1900.

——— The gold belt of the Blue Mountains of Oregon. In Twenty-second Ann. Rept., pt. 2, pp. 551-776. 1902.

——— Neocene rivers of the Sierra Nevada. In Bulletin No. 213, pp. 64-65. 1903.

——— Mineral deposits of the Bitterroot Range and the Clearwater Mountains, Montana. In Bulletin No. 213, pp. 66-70. 1903.

——— Tests for gold and silver in shales from western Kansas. Bulletin No. 202. 21 pp. 1902.

——— The production of gold in the United States in 1904. In Bulletin No. 260, pp. 32-38. 1905.

——— The production of silver in the United States in 1904. In Bulletin No. 260, pp. 39-44. 1905.

——— The Annie Laurie mine, Piute County, Utah. In Bulletin No. 285, pp. 87-90. 1906.

——— Notes on the Dahlonega mines. In Bulletin No. 293, pp. 119-128. 1906.

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——— ——— Geology and gold deposits of the Cripple Creek district, Colorado. Professional Paper No. 54. 516 pp. 1906.

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Ransome, F. L. Report on the economic geology of the Silverton quadrangle, Colorado. Bulletin No. 182. 265 pp. 1901.

——— The ore deposits of the Rico Mountains, Colorado. In Twenty-second Ann. Rept., pt. 2, pp. 229–398. 1902.

——— Preliminary account of Goldfield, Bullfrog, and other mining districts in southern Nevada; with notes on the Manhattan district by G. H. Garrey and W. H. Emmons. Bulletin No. 303. 98 pp.

Smith, G. O. Gold mining in central Washington. In Bulletin No. 213, pp. 76–80. 1903.

——— Quartz veins in Maine and Vermont. In Bulletin No. 225, pp. 81–88. 1904.

Spurr, J. E. Economic geology of the Mercur mining district, Utah. In Sixteenth Ann. Rept., pt. 2, pp. 343–455. 1895.

——— Geology of the Aspen mining district, Colorado; with atlas. Monograph XXX. 260 pp. 1898.

——— The ore deposits of Monte Cristo, Washington. In Twenty-second Ann. Rept., pt. 2, pp. 777–866. 1902.

——— Ore deposits of Tonopah and neighboring districts, Nevada. In Bulletin No. 213, pp. 81–87. 1903.

——— Preliminary report on the ore deposits of Tonopah. In Bulletin No. 225, pp. 89–110. 1904.

——— Ore deposits of the Silver Creek quadrangle, Nevada. In Bulletin No. 225, pp. 111–117. 1904.

——— Notes on the geology of the Goldfields district, Nevada. In Bulletin No. 225, pp. 118–129. 1904.

——— Geology of the Tonopah mining district, Nevada. Professional Paper No. 42. 295 pp. 1905.

——— The ores of Goldfield, Nev. In Bulletin No. 260, pp. 132–139. 1905.

——— Developments at Tonopah during 1904. In Bulletin No. 260. pp. 140–149. 1905.

——— Ore deposits of the Silver Peak quadrangle, Nevada. Professional Paper 55. 174 pp. 1906.

Spurr, J. E., and Garrey, G. H. Preliminary report on the ore deposits of the Georgetown mining district, Colorado. In Bulletin No. 260, pp. 99–120. 1905.

——— ——— The Idaho Springs mining district, Colorado. In Bulletin No. 285, pp. 35–40. 1906.

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——— Gold mines of the Marysville district, Montana. In Bulletin No. 213, pp. 88–89. 1903.

——— Notes on the gold veins near Great Falls, Md. In Bulletin No. 260, pp. 128–131. 1905.

WEED, W. H., and BARRELL, J. Geology and ore deposits of the Elkhorn mining district, Jefferson County, Mont. In Twenty-second Ann. Rept., pt. 2, pp. 399–550. 1902.

WEED, W. H., and PIRSSON, L. V. Geology of the Castle Mountain mining district, Montana. Bulletin No. 139. 164 pp. 1896.

——— ——— Geology and mining resources of the Judith Mountains of Montana. In Eighteenth Ann. Rept., pt. 3, pp. 446–616. 1898.

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COPPER.

COPPER DEPOSITS OF THE HARTVILLE UPLIFT, WYOMING.

By Sydney H. Ball.

INTRODUCTION.

While investigating the iron ores and pre-Cambrian geology of the Hartville iron range, Wyoming, in the field season of 1906, the writer visited the copper mines and prospects of this region with the exception of those in Muskrat Canyon. The following notes are the result of this work. Grateful acknowledgments are due to the mining men of the district, particularly to Messrs. Louis B. Weed, of Sunrise; C. A. Guernsey and W. T. Kelley, of Guernsey; Peter Hoyer, of Hartville; William Lauck and Joseph L. Stein, of Frederick; and Edwin Hall and Henry Metz, of Lusk.

The scant literature concerning these copper deposits is included in the following bibliography:

Mineral Resources U. S., 1882, U. S. Geol. Survey, 1883, pp. 229, 758–759.

Idem for 1883–84, p. 342.

Idem for 1887, p. 76.

Idem for 1888, p. 59.

Ricketts, Louis D., Ann. Rept. Territorial Geologist to Governor of Wyoming, January, 1888.

Idem for 1890, pp. 52–55, 77–78.

Knight, Wilbur C., Bull. Wyoming Exper. Sta. (Laramie, Wyo.) No. 14, Univ. Wyoming, October, 1893, pp. 135, 210.

Smith, W. S. Tangier, Hartville folio: Geologic Atlas U. S., folio 91, U. S. Geol. Survey, 1903.

The geography and the geology of the Hartville uplift are treated briefly in the article in this bulletin on the Hartville iron range (pp. 190–205). The geologic column consists of the following pre-Cambrian formations: A schist-limestone series, a quartzose and jasper series, diorites and gabbros and schists derived from them, granite, and diabase. Flat-lying Carboniferous rocks overlie the pre-Cambrian rocks. Of the two Carboniferous formations the Guernsey is the older and the Hartville lies upon it.

HISTORY AND PRODUCTION.

In 1878 John Fields, keeper of a stage station 14 miles north of Fort Laramie on the Black Hills and Cheyenne stage line, found copper ore piled beside a tunnel 1½ miles north of Frederick. Old trails, well worn, led up to the tunnel, and this may have been the work either of French trappers or of prehistoric races in search of the brilliantly colored chrysocolla. In 1879 the blanket vein of the Silver Cliff mine was discovered by John Madden, and two years later the Green Mountain Boy and the Sunrise deposits were discovered by Henry T. Miller, of Hartville. These mines and some of those of Muskrat Canyon were more or less actively exploited in 1881 and 1882, 75 miners having been employed at one time in the Sunrise mine. The more or less complete exhaustion of the copper deposits and the drop in copper prices, together with the great expense entailed in hauling ore and machinery to and from Cheyenne—distant 120 miles from the nearest mines—all contributed to their shut down. In 1888 the Sunrise mine was reworked for a few months. Later developments include the finding by Henry Metz of the Green Hope deposit in 1901, and the formation by Edwin Hall of the Copper Belt Mines Company at Rawhide Butte in 1906.

The production as given by Knight [a] is as follows:

Production of copper mines near Hartville, Wyo.

Sunrise mine	$209,282
Michigan mine (Muskrat Canyon)	40,000
Green Mountain Boy	30,000
	279,282

The estimate here given for the Green Mountain Boy is certainly $25,000, and probably $30,000, too low, which, together with the product of a number of smaller mines and prospects, would raise the total to $350,000.

ORE DEPOSITS.

GENERAL DESCRIPTION.

Geographically, copper is widely distributed in the Hartville uplift, and there is scarcely a square mile underlain by pre-Cambrian and Guernsey formations which does not contain copper showings. (See fig. 5, p. 192, for location of principal mines.) No very large mine has ever been discovered within the confines of the uplift, but copper is so widely distributed that the possibility of finding a mine or mines of some size is by no means unlikely.

[a] Bull. Wyoming Exper. Sta. No. 14, 1893, p. 135.

The copper deposits of the Hartville uplift are in the form of (1) ssure veins, (2) lenticular or globular masses of ore outcropping at he surface and pinching out at slight depths, and (3) blanket or edded deposits at the base of the Guernsey formation. It is admit-ed that development on the supposed fissure veins has not advanced ufficiently to determine their character beyond all doubt.

Malachite, chrysocolla, and chalcocite are much the most impor-ant ores. Of less common occurrence are tennantite (?), native cop-er, azurite, bornite, covellite, cuprite,[a] and chalcopyrite. Closely ssociated with the normal green chrysocolla, and evidently contem-oraneous with it, is a soft dark-brown substance. W. T. Schaller ound this to contain iron, copper, silica, and water, and it is proba-ly chrysocolla with considerable iron as an impurity. A yellowish-reen mineral fills fractures at several prospects. This is, according o W. F. Hillebrand, a copper arsenate. Chalcocite in particular as rule carries some silver, and native silver occurs at the Silver Cliff ine. Gold values are reported from iron-stained schist closely ssociated with the copper ores in several places. The gangue min-rals, in the main of later origin, include quartz, calcite, chalcedony, elenite, and barite.

Copper ores occur in the pre-Cambrian rocks and in the Guernsey ormation. No ore body has yet been found in the Hartville forma-ion or in the rocks overlying it. A possible exception is the pres-nce of slight malachite stains on blocks of Hartville sandstone in he talus overlying a copper deposit in Guernsey limestone in the enter of the NE. ¼ sec. 36, T. 27 N., R. 66 W. This malachite tain is, however, superficial and was probably deposited after the lock became a part of the talus. In consequence, in prospecting or copper, work should be confined to the area delineated on the eologic map in the Hartville folio[b] as being underlain by either re-Cambrian or Guernsey formations.

The more important copper deposits were probably deposited by escending waters and have no apparent connection with igneous rocks or, except in one place, with fault planes. The Guernsey formation, r some other which originally overlay it and which prior to the depo-ition of the Hartville formation was removed by erosion, was probably he original source of the ore of the larger deposits. The copper was robably included as a chemical or mechanical impurity in the Guern-ey formation. Such a view necessitates the former existence of pre-Carboniferous copper deposits in the area from which the Guernsey ormation was derived. Possible examples of such deposits are escribed as fissure veins in the following section.

[a] Mineral Resources U. S., 1882, U. S. Geol. Survey, 1883, p. 758.

[b] Geologic Atlas U. S., folio 91, U. S. Geol. Survey, 1903.

FISSURE VEINS IN PRE-CAMBRIAN FORMATIONS.

The Copper Bottom prospect, owned by Henry Metz and situated in the south-central part of the SE. ¼ sec. 23, T. 29 N., R. 65 W., is located probably on a fissure vein. At the time of the writer's visit the shaft was 15 feet deep. The country rock is a slightly silicified dense yellowish limestone of pre-Cambrian age, which is cut by thin seams of hematite. The vertical vein, which strikes N. 20° W., cuts across the steeply dipping limestone. There is a fault of small throw on the east side of the vein, and fragments of limestone are included in the vein matter. On the east side of the shaft the vein is 4 inches wide at the surface and 22 inches at the bottom of the shaft; on the west side the vein comes in 3 feet from the bottom and there only as a thin stringer. The limestone for a distance of 1 foot on either side of the vein is heavily iron stained. An assay of an average sample collected by the writer across the vein on the east side of the shaft, 15 feet from the bottom, contained a trace of gold, 2 ounces per ton of silver, and 24.64 per cent of copper. The predominant ore is the brownish form of chrysocolla, blotched with irregular masses of green chrysocolla in the center of which is some malachite and rarely a little azurite. Tennantite[a] occurs in irregular masses up to 1 foot in length. Although chrysocolla is on the whole slightly older than malachite and the latter older than azurite, these ores with tennantite are approximately of the same age. Incrusting tiny cavities in this ore is some quartz, which in turn is coated with younger calcite. Clearly later than these ores and gangues and occurring in cracks in them are knife-edges of malachite, azurite, and a black sooty copper oxide or sulphide. The thickening with depth, together with its position along a fault, lead to the belief that this deposit is the oxidized portion of a fissure vein. The apparent thickening with depth may, however, be local.

The Charter Oak prospects, owned by Lauck & Stein, are situated on the south side of McCanns Pass, near the center of the SE. ¼ sec. 20, T. 27 N., R. 65 W. The deposits lie beneath apparent gossans of limonite and hematite, in pre-Cambrian muscovite schist and gray quartzose beds. Malachite, chrysocolla, and chalcocite occur in fractures, in one place within a cupriferous belt 4 feet wide and in another place along a vein 4 feet wide cutting across the vertical schist. The schist near the copper is said to assay from 80 cents to $27 in gold and 2 to 5 ounces of silver. The amount of development at this point is small, but these deposits have the appearance of being the oxidized zone of a copper vein.

[a] W. T. Schaller states concerning specimens submitted to him: "Both samples contain the constituents of, and probably are, tennantite."

At several places near Haystack Peak, copper minerals fill tiny fractures or incrust cavities in pegmatite or pegmatitic quartz dikes. Chalcopyrite and chalcocite are original and malachite and covellite are their alteration products. Sulphides are rather abundantly present in the center of the NE. ¼ sec. 26, T. 27 N., R. 65 W., as cement to a breccia of schist. A sample collected at one of these prospect shafts, on the dump, which at the time of examination was boarded over, gave a trace of silver, but no gold, copper, or nickel.

LENSES OF COPPER ORE DEPOSITED BY DESCENDING WATERS.

The most common copper deposits in the Hartville uplift are lenticular or wedge-shaped masses of carbonates, silicates, and oxides and secondary sulphides which narrow with depth and finally disappear. These deposits, which occur in the Guernsey and several of the pre-Cambrian formations, are believed to have been laid down by descending waters, the ore presumably having been leached from the Guernsey or from some formation that was once superimposed upon it, but was removed by erosion prior to the deposition of the Hartville formation.

Lenses in the Guernsey formation.—Copper deposits in the Guernsey formation are practically confined to the immediate vicinity of Guernsey, the only deposit of consequence being that of the Green Mountain Boy.

The Green Mountain Boy mine is situated approximately half a mile east of the town of Guernsey, at the head of a broad valley. The production has been variously estimated at 300 to 500 tons, valued at $36,000 to $60,000. The ore is said to have averaged 37 per cent copper, with from one-third to one-half ounce of silver to each per cent or unit of copper, the total values averaging at the time of shipment $155 per ton. The silver, which was closely associated with chalcocite, was patchy in distribution, some assays of high value having been obtained.

The country rock is the upper part of the light-gray or white horizontal Guernsey limestone which at the horizon of the main workings contains many lenticular masses of brown flint. The flint nodules are from 2 inches to 4 feet long, and from one-half inch to 6 inches wide. Calcite-lined cavities 2 to 3 feet long occur in the limestone. The original lens was of chalcocite and is stated to have been 60 feet long, 30 feet wide, and from 5 to 9 feet thick. The long diameter of this podlike mass lay east and west across the valley. At the surface considerable malachite was associated with the chalcocite, but as the lens was followed into the hill malachite decreased in amount. The open cut and the three tunnels from it now open to inspection show but little ore, and the tunnels are barren 30 feet southwest of

their entries. Twenty feet immediately beneath the ore lens a tunnel was driven 50 feet, and this, with the exception of a few small stringers of ore, is also barren.

The copper ores now seen here occur in three ways—as replacements of flint nodules, in veinlets, and as patchy malachite stains in the limestone. Chrysocolla, less commonly malachite, and still more rarely chalcocite replace the flint nodules. The three ores are contemporaneous. In a number of places the exterior of the flint is unaltered, the replacement having begun at the center. As seen under the microscope the copper minerals invade the chalcedonic quartz as irregular ramifying bodies with rounded ends, resembling the fronds of a maidenhair fern. The predominance of the replacement of flint by chrysocolla (a copper silicate) is probably due to the reaction of the siliceous flint on the copper-bearing solutions, as is the predominance of chrysocolla over malachite in copper lenses in pre-Cambrian schist. Since replacement the flint nodules have been cracked, and along these fractures are films of malachite. Fractures filled with veinlets of malachite and chrysocolla are common on the sides of the open cut and near the mouths of the tunnels. These stringers were evidently leached by descending waters from the main ore body or from the replaced flint nodules.

The ore body of the Green Mountain Boy was distinctly limited below, and scarcely a copper stain is visible 20 feet beneath the bottom of the canoe-shaped mass of chalcocite. The copper ores were evidently deposited by descending water, the mass leached probably having been the upper portion of the Guernsey formation. The ore body was largely a replacement deposit, in part of limestone and in part of flint. Since the original deposition the ore body has been fractured and surface waters have filled the fractures with malachite and chrysocolla.

Lenses in pre-Cambrian limestone.—The most widely distributed form of copper deposit in the Hartville uplift occurs in pre-Cambrian limestone, as a rule within less than 50 feet of the base of the overlying Guernsey formation. The deposits, in places at least, give out within 20 feet of the surface.

The ore occurs in veinlets along bedding planes, many of which are planes of differential movement, accompanied by brecciation; in veinlets along joint faces; and as replacements of limestone. Malachite predominates over green chrysocolla; and azurite, brown chrysocolla, chalcocite, and yellowish-green arsenate also occur locally. Mr. Peter Hoyer, of Hartville, reports that a canoe of chalcocite 12 to 14 feet long, 1½ feet wide, and 1 to 2 feet thick was encountered at the surface at the Empire mine, half a mile southwest of Sunrise. Quartz and calcite are the chief gangue minerals, and the gangue material is in

many places either an iron-stained limestone or hematite. The veinlets of ore do not extend beyond these iron-rich substances in so many places that the natural inference is that the iron acted as the precipitant. Under the microscope a thin section of this ore shows that the copper ores occur as veinlets cutting the hematite and limestone and rim the hematite as if it had acted as the precipitant. Limonite is contemporaneous with the copper minerals. Since the hematite is locally the iron-rich base of the Guernsey formation recrystallized, extending down into joints in the limestone enlarged by solution, it is possible that the ore is all of post-Carboniferous age. The lenses of copper ore in pre-Cambrian limestone are certainly in some places and probably everywhere post-Carboniferous in age, and were formed by descending waters, the probable source of the copper having been the Guernsey formation.

Lenses in schist and other pre-Cambrian formations.—Similar lenses of ore with definite downward limitations occur in pre-Cambrian schist, quartzose, and jaspery rocks and in the chloritic schist derived through mashing from basic igneous rocks. In schist he ores, chrysocolla, and malachite, and in some places chalcocite and azurite, occur as thin sheets in the planes of schistosity and in small cross fractures. Microscopic examination also shows, in addition to innumerable tiny fractures filled with malachite, some replacement of quartz by malachite. At some places these deposits decrease in width with depth and at others they extend downward from blanket deposits of the Guernsey sandstone. The majority of them, at least, are thought to have been formed by descending waters, and the source of many was probably the Guernsey formation. Since the gray quartzose rocks and the jasper are very brittle, the ramifications of the copper veinlets through them are most complex.

Lenses in iron ore and heavily iron-stained jasper.—The most important example of the lenses in iron ore and jasper is the Sunrise mine, now the most productive iron mine west of the Mississippi, but in the eighties an important copper mine. It is situated on the southward-facing slope of a steep hill in the north-central portion of sec. 7, T. 27 N., R. 65 W. Its total copper output is given by Knight as 1,395,287 pounds, valued at $209,282. The copper content ranged from 6 to 20 per cent, with an average yield of 15 per cent. Knight states further that the ore carried from 2 to 3 ounces of silver per ton. The slag from the Fairbank furnace, where the ore was smelted, is now being shipped to smelters by C. A. Guernsey, of Guernsey, who states that it averages 5 or 6 per cent of copper. Malachite, leached from the slag since the shut-down of the furnace, occurs upon the surface and in the cavities of the slag fragments.

The country rock of the copper ore at Sunrise is schist, iron ore (hematite), and an impure flint which is stained by either limonite

or hematite and which is evidently a relatively shallow alteration product of the schist, formed in pre-Carboniferous time.

The copper workings of the Sunrise mine have largely been cut away or rendered inaccessible by the Sunrise open cut, and at present but small portions of the ore body are open to investigation. Concerning the form of the deposit, Ricketts states[a] that it lies in lenticular bodies which expand and contract irregularly, in gashes, and in pear-shaped bodies, one of which was over 30 feet in height and 20 feet in diameter. These were irregularly distributed through the country rock. He also writes: "A stringer of ore was followed farther up the hill and led up vertically through the hematite to the overlying [Guernsey] limestone cap, where the hematite ceased. The copper, however, could be followed up as a stringer along jointing planes of the limestone and led to several small bodies of ore spread out parallel to bedding planes. A very interesting specimen from this horizon was a piece of copper ore with numerous pieces of Carboniferous fossils impressed on one side of it."[b] As seen in cross section on the side of the Sunrise open cut, the copper ores stop 60 feet below the former surface and no trace of copper is seen in any of the workings on the first, second, or third levels of the iron mine, although these completely undermine the ground beneath the deposit.

Within these lenticular or pear-shaped bodies the copper ores occur as ramifying veinlets and masses occupying joint and irregular fractures and cavities in the country rock. The copper ore is especially abundant in the more heavily iron-stained portions of the flint and in hematite. The ores, named in the order of their importance, are chrysocolla, malachite, chalcocite, azurite, and native copper. Ricketts states that copper oxides were present in considerable amounts. Malachite is finely granular, although in cavities it forms tufted aggregates of acicular crystals or mammillary masses of radiate structure. The glassy green or brown chrysocolla in cavities is botryoidal. Chalcocite, chrysocolla, and malachite are practically contemporaneous, the last two in particular replacing each other along the length of the veinlets. Azurite, which is especially characteristic of the immediate surface, is on the whole somewhat younger than the others, although in places contemporaneous with them.

Quartz and calcite and more rarely chalcedony, selenite, and barite occur as gangues. In general quartz is younger than the copper minerals, and either incrusts them in vugs or cuts them in veinlets. The quartz, though as a rule white, is in places stained green by copper salts. Many crystals of white or lemon-yellow calcite coat the quartz and are hence younger. The colorless gypsum called selenite is also younger than the ores, although in a few places it incloses fibers

[a] Ann. Rept. Territorial Geologist to Governor of Wyoming, 1888, p. 66.
[b] Idem, p. 66.

of malachite. George Botsford, of Sunrise, reports that he has observed barite crystals covering the copper ores. During the deposition of these ores there was probably some slight recrystallization of hematite, since between fractures containing copper minerals the hematite is softer and of slightly coarser grain than that farther from the copper.

Two thin sections of copper ore in hematite were examined under the microscope. In each, malachite and chrysocolla fill fractures most intricately cutting the hematite, and in each the copper minerals partly replace hematite.

Field evidence in the Hartville uplift appears to show that hematite has been an important precipitant of copper. In addition to the phenomena at the Sunrise mine, the copper is intimately associated with an older, heavily hematized gangue in the pre-Cambrian limestones, and the bedded deposits at the base of the Guernsey formation are confined largely to heavily hematized portions of the sandstone.

The association of copper ores and hematite is not extraordinary, but deposits in which hematite is the country rock and is older than the copper ore are unusual. At the Soudan[a] and Chandler[b] mines, on the Vermilion Range in Minnesota, native copper and various carbonates and oxides secondary to it occur in fracture zones in iron ore. Hobbs refers the precipitation of the copper to the oxidation of ferrous iron compounds. Haworth[c] reports films of native copper in fractures in "Red Beds" at Enid, Okla., which are rich in hematite. He believes that the soluble salts of copper were reduced to oxides by the hematite and that the ferrous sulphate which formed, in the presence of free sulphuric acid, reduced the copper oxides to the native state. At the Sunrise mine ferrous salts might have been formed from hematite itself and by their oxidation precipitated the copper minerals.

In the Sunrise mine lenticular or pear-shaped masses of copper ore were deposited not only after the iron ores had been formed, but also after they had been fractured, the copper deposition having occurred in post-Guernsey time. The distinct termination of the ore with depth may indicate that it was deposited by descending waters, and since copper ore extends upward into the Guernsey formation that formation was presumably the original source.

The old Village Belle copper mine, now a part of the Sunrise mine, appears to have been of similar character, although native copper is said to have been rather common.

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[a] Eby, J. H., and Berkey, C. P., Proc. Lake Superior Min. Inst., vol. 4, 1896, pp. 69-79. Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey, vol. 5, 1900, p. 885. Clements, J. M., Mon. U. S. Geol. Survey, vol. 45, 1903, pp. 113, 189. Hobbs, W. H., Am. Geologist, vol. 36, 1905, p. 185.

[b] Clements, J. M., Mon. U. S. Geol. Survey, vol. 45, 1903, p. 184.

[c] Haworth, E., Bull. Geol. Soc. America, vol. 12, 1900, pp. 2-4.

BLANKET DEPOSITS AT THE BASE OF THE GUERNSEY FORMATION.

Characteristics.—Copper ores are segregated in the sandstone at the base of the Guernsey formation at a number of places in the Hartville uplift. Malachite and chrysocolla and less constantly azurite and chalcocite are the more common ores, although native copper, silver, and copper arsenate also occur. Shipments of picked ore have averaged over 17 per cent of copper, and either gold or silver values are present in much of the ore. These ores occur as lenticular or tabular masses in the sandstone, where the copper minerals may form the cementing material of the sandstone. They also fill joint cracks and irregular fractures or form nodules. The ore bodies are in most places unconnected with fissures and nowhere with igneous rocks. No igneous rocks other than those of pre-Cambrian age are known in the Hartville uplift. The greatest dimension of these tabular ore bodies is horizontal, and they do not extend into the overlying limestone member of the Guernsey formation. In many places stringers of ore descend into the pre-Cambrian schist or limestone, which underlies the Guernsey formation unconformably, and at least in most of such stringers this ore has been leached from the blanket deposits. The bedded ore body is in general but 2 or 3 feet thick, although where it lies upon pre-Cambrian limestone the ore in the ramifying sandstone masses extending into the irregularities of the pre-Cambrian limestone is locally 20 feet thick. At the bottom of such pockets and small sink holes the ore has been concentrated against the limestone, forming local enrichments. As a rule the lateral extent of these deposits is small, although some of them are considerably over 100 feet in diameter.

In prospecting these deposits the lower limit of the flat-lying Guernsey formation immediately above the tilted pre-Cambrian limestones and schists should be followed. The geographic position of this line is shown on the geologic map of the Hartville quadrangle[a] by W. S. Tangier Smith and N. H. Darton. Iron-stained masses of the sandstone especially should be examined, since such portions are more favorable for copper ores. While no deposit of this class has yet proved to be of great size, the ore is cheaply mined by tunneling, and some of it can be worked at a profit.

As type examples of this form of deposit the Green Hope and Silver Cliff mines are described.

Green Hope mine.—The Green Hope mine is situated on the upper slope of a valley in the NW. ¼ sec. 26, T. 29 N., R. 65 W. Its product is variously estimated at 400 to 525 tons, carrying from 15 to 27 per cent and averaging 17 per cent of copper. The deposit has been exploited by two tunnels, from which three sinuous galleries extend.

[a] Geologic Atlas U. S., folio 91, U. S. Geol. Survey, 1903.

The base of the Guernsey formation is here a heavily iron-stained and slightly conglomeratic sandstone that is locally cemented with lime carbonate. The underlying pre-Cambrian limestone prior to the deposition of the Guernsey formation had a very uneven surface, roughened through the development by solution of enlarged joints, small sink holes, and irregular cave galleries. The ore-bearing sandstone, which is as a rule but 3 feet thick, extends down into these cavities, some of which are 20 feet below the normal contact of the Guernsey and pre-Cambrian formations. The complexity of the ramifications of such masses of copper-bearing sandstone is indicated by the fact that they are in places separated from one another by masses of pre-Cambrian limestone on the sides of the workings. Ore does not extend from the sandstone into the limestone member of the Guernsey formation. The mineralized zone is exposed for 150 feet along the valley side.

Malachite, chrysocolla, azurite, and chalcocite form the cement of the sandstone. The vividly colored copper-stained sandstone alternates sharply with patches of unstained pink or gray sandstone. The same minerals, together with the yellowish-green copper arsenate already mentioned, fill fractures in the copper-stained and unstained sandstone, forming veinlets and nodules of ore. Chalcocite is particularly common in this form. Some of these nodules fill cavities once occupied by pebbles of pre-Cambrian limestone which have been removed by solution. Where the cavities have not been completely filled by the ore, malachite forms tufted crystal aggregates, whereas chrysocolla occurs as botryoidal masses. White or yellowish calcite, of later origin than the copper minerals, incrusts them, and in many places films of bluish-white chalcedony cover the calcite. Although these gangue minerals are clearly of later origin than most of the ore, here and there a little malachite coats the chalcedony, indicating that the ore was undergoing recrystallization during a considerable period of time.

Malachite, chrysocolla, and azurite have been leached from this blanket deposit down into the pre-Cambrian limestones as irregular stains and as stringers descending from the blanket deposit.

Two thin sections of ore from the Green Hope mine were examined microscopically. One is a well-assorted quartzose sandstone in which the half stained by copper is separated with line-like sharpness from that stained by limonite. The portion of the rock without copper has as a cement finely divided kaolinitic matter, with probably a little sericite. In the other portion this kaolinitic substance is replaced by malachite either in a very finely divided and almost flocculent condition or in fibrous aggregates, the fibers of some of which are radially arranged. In one or two places malachite enters the quartz grains in blunted embayments and probably replaces it.

In the second thin section chalcocite as well as malachite forms th cement. Further, both minerals fill many fractures in the quart grains. The areas of the copper minerals in the sandstone are s large and many of the quartz grains have been so greatly eaten int by malachite and chalcocite that it is evident that both copper min erals have replaced the quartz to an important extent.

Silver Cliff mine.—The Silver Cliff mine is three-fourths of a mil southwest of Lusk, the deposit crossing low hills in a southerly direc tion. Ore from this mine is reported to have assayed as high a $150 per ton in silver and copper. The pre-Cambrian formatio here is a steeply dipping muscovite schist interbedded with thi lenses of limy schist. The flat-lying Guernsey formation above it i dropped down by a fault on the west side against the pre-Can brian. This fault courses S. 10° W. and has a displacement of 2 feet.

The pre-Cambrian schist along this fault contains malachit chrysocolla, and chalcocite, and a few leaves of native silver occ on fracture planes in the schist. The exposures are not sufficient t determine definitely whether this is a pre-Cambrian vein, wheth the ore in the pre-Cambrian rocks was leached from the overlyin Guernsey formation, or whether the copper ores in both pre-Can brian and Carboniferous terranes were deposited by waters ascen ing along the fault plane.

In the iron-stained sandstone at the base of the Guernsey form tion along the fault line is a blanket of copper ore from 20 to 40 fe wide, 2 to 5 feet thick, and several hundred feet long. In minera ogical composition the ore is in all essential particulars similar that of the Green Hope mine previously described, except th native copper is reported to occur near the surface. A thin section the Guernsey ore shows that limonite, malachite, and chalcoci replace the matrix of the sandstone, which is kaolinitic material a calcite. Kaolinized grains of feldspar are likewise heavily stain by malachite that apparently replaces the kaolinitic material. T copper minerals also replace quartz and occur in fractures in t quartz grains.

Origin of deposits. In considering the origin of these blank deposits the following facts must be taken into account: First, th lie upon an impervious stratum, and, with the exception of the Silv Cliff deposit, have a definite downward limit; second, the ores a mineralogically like those of the Sunrise and Green Mountain B mines, which are known to be deposited by descending waters; thi the deposits are, with the exception of that at the Silver Cliff mi unconnected with fractures; fourth, they occur in a formation whi is younger than any known igneous rock in the Hartville uplift; a fifth, in many places they are associated with and structurally rese

ole recrystallized detrital iron ores which occur at the base of the Guernsey formation and which have been derived from the mechan-ical breaking down of pre-Cambrian iron-ore bodies. (See pp. 194–195.)

The deposits were not laid down in the sea in the form in which they now exist. This is shown by the fact that they are not evenly dis-tributed at the base of the Guernsey formation, as well as by the straight-lined contacts between copper-stained masses and those that are unstained by it and by the occurrence of the copper minerals as veinlets in fractures. It is believed, however, that the blanket deposits were segregated by descending and laterally moving waters from copper that was widely distributed in the Guernsey formation. This copper, presumably derived originally from fissure veins in the pre-Cambrian rocks, was probably included in the Guernsey deposits as either a mechanical or a chemical impurity at the time that forma-tion was laid down beneath the sea. As Emmons[a] suggests, clays may have precipitated the copper from the sea waters, exercising the peculiar selective property called adsorption by Kohler.[b] That kaolinitic substances have acted as powerful agents in the recrystal-lization of the ores is shown by the replacement of the kaolinitic material both in the cement of the sandstone and in the feldspars. From analogy with the iron deposits at the base of the Guernsey formation (see pp. 198, 203), it is probable that, had heavy fragments of copper ore formed a part of the sand of the Carboniferous sea, they would naturally be concentrated in the small sink holes characterizing the surface of the pre-Cambrian limestone. Fragmental copper ore is, however, not observed in any of the deposits. The deposit at Silver Cliff, as before stated, may be of different origin, and the copper here may have been deposited by water ascending along the fault.

THE COPPER BELT MINES COMPANY'S HOLDINGS.

For convenience the mines and prospects of the Copper Belt Mines Company will be described together. These properties, which are grouped around the corner common to sections 2, 3, 10, and 11, T. 30 N., R. 64 W., lie on rugged hills half a mile west of the highest peak of the Rawhide Buttes. The rocks in the vicinity are of pre-Cambrian age and comprise an interbedded series of limestones and schists, and a granite and its associated pegmatite intrusive in them, which are probably equivalents of the pre-Cambrian rocks near Hart-ville. The limestones are crystalline, fine to medium grained, and white. The schists are more thoroughly metamorphosed than those in the vicinity of Hartville. The folding of the series is in many places very close, and the strike of the formations is broadly from northeast to southwest.

[a] Emmons, S. F., Bull. U. S. Geol. Survey No. 260, 1905, p. 232.

[b] Kohler, Ernest, Zeitschr. prakt. Geologie, February, 1901, pp. 44–59. See also Sullivan, Eugene, Economic Geology, vol. 1, 1905, pp. 67–73.

The Lucky Henry incline, 288 feet deep, has a hanging wall of lime stone and a foot wall of iron-stained schist. The limestone, whic dips 45° S. 50° E., is but 2 to 4 feet thick, and in front of it lies second schist band. Since the dip varies somewhat in amount, th hanging wall leaves the incline at several points, and at such place drifts extend to it. The ore lies in the schist against the hangin wall in two lens-shaped masses separated from each other by barre schist. These lenses are from 1 to 6 feet thick and appear to con tinue downward from the surface to the bottom of the incline with width of 15 feet or more, although there may be breaks in the or where the foot wall is not exposed. Within the lenses the schis contains ramifying veinlets and stringers of malachite and chryso colla, with a little chalcopyrite. Chalcopyrite first appears at 50 fee from the surface and continues to the bottom. Veinlets of late origin, which are filled with calcite or quartz, cut the ore stringer Edwin Hall, the president of the company, states that the lenses ru from 2 to 8 per cent of copper, and that the iron-stained schist aroun the lenses carries from $1 to $12 in gold per ton, with an average c $3, and from 2 to 5 ounces of silver per ton. The lower 10 feet c the incline is slightly moist and surface water now follows the schis hanging wall downward. Development has not proceeded far enoug to determine beyond doubt how this deposit was formed. Ascendin water may have been the agent. If this is true, the original sulphide have been largely changed to carbonates and silicates by surface water descending along the schist foot wall.

The Gold Hill and Omaha shafts are situated on a band of schis from 7 to 20 feet wide lying between two limestone beds. At th Gold Hill shaft the dip is 45° S. 40° E., and at the Omaha 42° S. 60 E., the schist band between the two describing an S. In the Gol Hill shaft the ore is in a cross vein bounded by fracture planes whic dip 60° S. 75° W. This vein is 6 feet wide and beneath it is a 2-foo belt of iron-stained schist which is said to assay in gold $4 per to Malachite, chrysocolla, and a little chalcocite occur within the shoo in veinlets parallel to and cutting the schistosity. A quartz vei parallel to the schistosity is shattered and in its fractures are stringe and nodules of chalcocite and bornite, probably original sulphide These are partially altered to chrysocolla, malachite, and azurite.

At the Omaha incline chrysocolla, malachite, azurite, chalcocit and chalcopyrite occur in schist in stringers both parallel to th schistosity and cutting it. Barite is present as a gangue. The or bearing zone reaches a maximum width of 4 feet and Hall states tha it assays 2 per cent copper, although by hand picking the content could be raised to 4 per cent. The copper-bearing lens is expose more or less continuously for 204 feet. The open cut on the Emm claim discloses a fracture zone in schists containing quartz lense

arallel to the schistosity in which malachite, green and brown chrysocolla, azurite, chalcocite, and chalcopyrite occur in cavities formed by the fracturing of the country rock. The ore carries from 3 to 30 per cent of copper, masses of chalcocite weighing 47 pounds having been found. Malachite, chrysocolla, and chalcocite occur in limestone on the Omaha, Emma, Lucky Henry, and Metz claims. These deposits are probably similar to those described under the heading "Lenses in pre-Cambrian limestone" (pp. 98–99).

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NICKEL, URANIUM, ETC.

CARNOTITE IN RIO BLANCO COUNTY, COLO.

By Hoyt S. Gale.

INTRODUCTION.

In September, 1906, while the writer was engaged in a survey of coal fields in the upper valleys of White and Yampa rivers in northwestern Colorado, his attention was called to the reported occurrence of an ore of uranium that was then and is now attracting considerable interest from various parts of the State. The prospects lie just east of the border of the Danforth Hills coal field and the material occurs in rocks the study of whose stratigraphy has formed an important part of the writer's field work for the last two seasons. In the spring of 1906 a party, including Mr. E. L. White, State commissioner of mines, and Prof. Herman Fleck and W. G. Haldane of the school of mines at Golden, Colo., visited these prospects, and their report is expected at an early date.

LOCATION.

The prospects lie near the valley of Coal Creek, about 14 miles by wagon road northeast of Meeker, the county seat of Rio Blanco county. Meeker is usually reached by stage from Rifle, a station 45 miles distant on the Denver and Rio Grande Railroad, the trip occupying a day. The claims now located (eight or ten in number) are situated 1½ miles east to southeast of the locality known as "The Transfer," on Coal Creek, where lumber hauled from the mills on Sleepy Cat Mountain is transferred to the larger wagon loads to be taken into Meeker.

CARNOTITE.

The name carnotite was given in 1899 by E. Cumenge and C. Friedel to a canary-yellow ocherous pigment that was found impregnating a siliceous sandstone in Montrose County, Colo.[a] Carnotite has also been discovered in San Miguel and Mesa counties in Colorado and in adjacent counties of Utah.

[a] Merrill, G. P., The Nonmetallic Minerals, 1904, p. 322.

The mineral carnotite is of use as a source of the rare elements uranium and vanadium. It is also reported to have been tested and found to contain the rarer element radium.[a] It is readily dissolved in acids and may be treated in this way for the commercial production of uranium salts. The chief use of uranium is as a pigment in painting on porcelain, in photography, and as a color in glass manufacturing.[b] It has been employed experimentally in the manufacture of alloys of iron and aluminum. It increases the hardness and elasticity of steel and also of aluminum, but as yet has not been put to much practical use for this purpose.

A description of the carnotite occurrences in western Colorado and a discussion of the chemical nature of the mineral will be found in a paper published by Hillebrand and Ransome in August, 1900.[c] In this paper the following conclusions as to the general nature of carnotite are reached:

> The body called carnotite is probably a mixture of minerals of which analysis fails to reveal the exact nature. Instead of being the pure uranyl-potassium vanadate, it is to a large extent made up of calcium and barium compounds. Intimately mixed with and entirely obscured by it is an amorphous substance—a silicate or mixture of silicates—containing vanadium in the trivalent state, probably replacing aluminum. The deposits of carnotite, although distributed over a wide area of country, are for the most part, if not altogether, very superficial in character and of recent origin.

The Rio Blanco County carnotite is found in the Dakota sandstone, a group of sandstone ledges of which several are very massive, interstratified with some shaly beds. This formation has a thickness of 700 feet or more. The carnotite is found at the summit of the hogback ridge formed by the lowest and most massive of the sandstones. In the principal group of deposits seen the carnotite occurs in association with fossil or silicified wood. This fossil-wood layer is apparently an original stratum of the Dakota sandstone, for it may be traced along the strike of the beds for a mile or more. The carnotite itself is in the form of a bright-yellow film or crust with the appearance of having been deposited from solution, coating the silicified wood and filling cracks in it and to a less extent in the neighboring sandstone. In only one place the mineral was found as an impregnation in the Dakota sandstone apparently without association of silicified wood.

The mineral itself, scraped from the rock to a glass slide, immersed in liquid and covered with a thin glass, shows on magnification minute granular patches, transparent and yellow in color. W. T. Schaller examined some of this material in the Geological Survey laboratory and found a few crystals showing minute hexagonal form

[a] Eng. and Min. Jour., vol. 77, 1904, p. 673.
[b] Eng. and Min. Jour., vol. 76, 1903, p. 46.
[c] On carnotite and associated vanadiferous minerals in western Colorado: Am. Jour. Sci., 4th ser., vol. 10, 1900, p. 120.

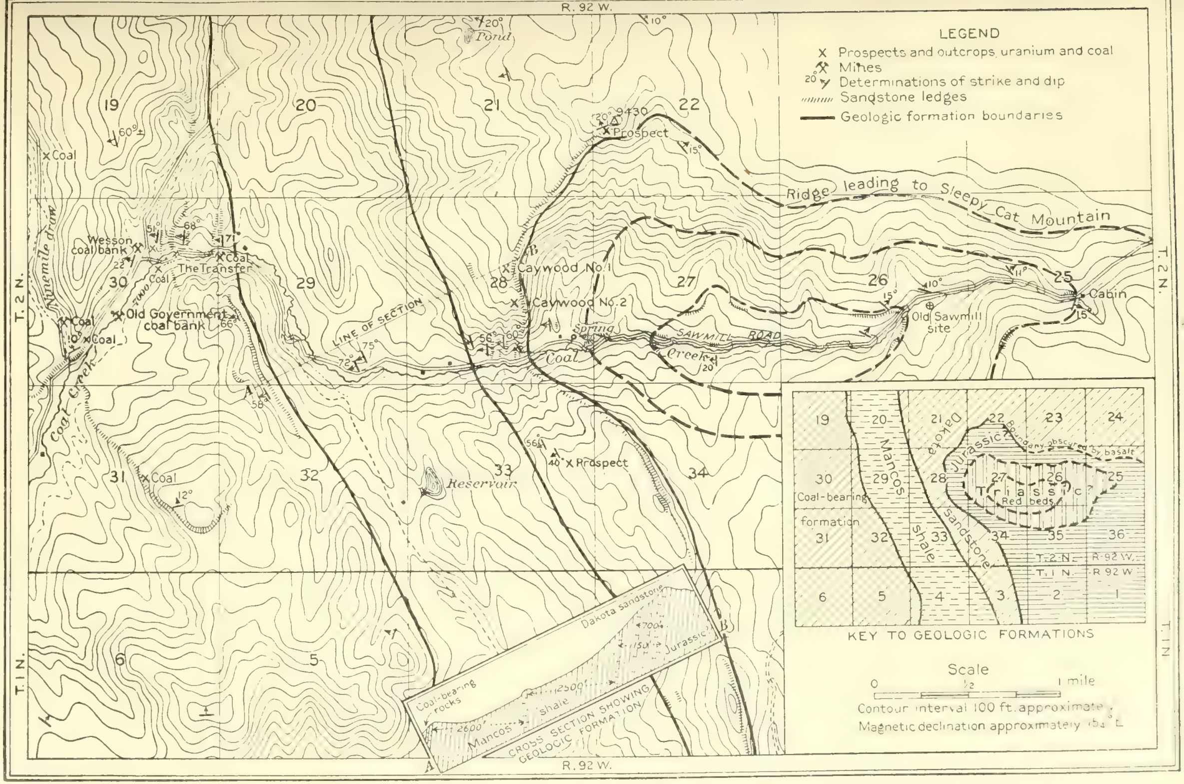
and an appreciable thickness, but too minute to give interference figures. In this respect it probably varies in character from the Montrose County carnotite, which is reported to be composed of "exceedingly fine, dust-like particles without crystal outlines and acting so faintly on polarized light as to at first seem almost amorphous," although a few exceedingly minute crystals are also mentioned in the description of that material.

The Montrose County carnotite is reported to be found in the La Plata sandstone, which is of Jurassic age, and the mineral therefore occurs in an older geologic formation than the carnotite of Rio Blanco County, which is found in the Dakota sandstone. Since, however, in both localities the carnotite was evidently deposited in these rocks long after the time of their formation as such, this difference has no especial significance relating to a differing mode or time of formation of the mineral itself.

GEOLOGY OF THE COAL CREEK DISTRICT.

The summit of Sleepy Cat Mountain is a peak of about 10,800 feet elevation, capped by basaltic lava representing a succession of surface flows that probably took place in late Tertiary time. The bowlders of this basalt strew the spurs and ridges surrounding the peak and obscure much of the structure of the underlying sediments. Coal Creek rises on the west flank of Sleepy Cat Mountain and flows nearly due west for 6 miles in a rather deep, narrow valley. About midway in this portion of its course the creek has cut its valley into the crest of an anticlinal fold or dome in the rock strata, exposing formations that are doubtless of Triassic age. (See geologic map, Pl. III.) Along the upper half of this stretch of Coal Creek the rocks dip to the east or northeast, toward Sleepy Cat Mountain. Down the creek bed west of the fold these same rock beds may be recognized dipping westward, in the direction the creek is flowing, and as they pass beneath water level they are covered by successively younger formations. At the lower end of its narrow valley the creek passes through a gateway in large ledges of white quartzite and sandstone, west of which it emerges into a long, straight, northwest-southeast valley. The white sandstone ledges represent, in part at least, the formation so widely known as the Dakota sandstone. The depression immediately east of this sandstone and quartzite ridge is formed upon shaly strata showing in outcrops of various colors, in the main shades of pink and red. It is suggested that these underlying strata may be of the same age as the Gunnison formation of the Anthracite-Crested Butte area.[a] The fact that, so far as the writer knows, no identifiable fossils have as yet been collected from the formations including and below the Dakota in this locality or near vicinity causes some doubt as to the

[a] Eldridge, G. H., Geologic Atlas U. S., folio 9, U. S. Geol. Survey, 1894.



GEOLOGIC MAP OF UPPER COAL CREEK VALLEY AND VICINITY, RIO BLANCO COUNTY, COLO.

proper designation of these lower formations. The rock strata, however, form a series fairly comparable with the formations known east of the Rocky Mountain ranges, and it is on the basis of similarity of character of the rocks themselves that the geologic names are given.

Below the gap in the Dakota ledges Coal Creek emerges into an open valley, from which, after making a short turn toward the north, it once more turns westward and cuts into the sandstone hogbacks of the coal field. Half a mile or so beyond, it turns to the south toward White River. The valley between the coal-field hogbacks and the Dakota hogback is about 1½ miles wide and is eroded on a formation of comparatively weaker shales. It is divided about midway by a minor hogback ridge due to the presence of some harder sandy layers. The total thickness of these shaly strata is considerably over a mile. Just above the Dakota ledges the shale is very black, dense, and in many places slaty, and in this position on the north slope of Sleepy Cat Mountain a number of fossils were found that are known to be of Benton age. The geologists of the Hayden survey mapped this whole predominatingly shaly formation (except a few hundred feet at the top that were placed with the Fox Hills formation) as the Colorado shale. As a single unit the whole group of strata above the Dakota sandstone and below the coal-bearing formation has been called the Mancos shale in the report on the Yampa coal field.[a]

Above the Mancos shale the coal-bearing sandstones and shales attain a thickness of something over a mile, and in other parts of the field these rocks are succeeded and overlain by still later formations. The lumber camp known as "The Transfer" is in the rocky gorge where Coal Creek enters the lowermost ledges of the coal-bearing beds. All of these rocks, occupying the interval from the beds below the Dakota ledges up to the sandstone ledges near "The Transfer," dip westward at rather high angles, varying from about 55° to 75°. (See cross section, Pl. III.)

PROSPECTS.

CAYWOOD CLAIMS.

A number of claims on which only prospect pits had been dug were visited in company with Mr. Gilbert Wesson, of Meeker. The best showing of carnotite was in a shallow pit, said to be known as the Caywood No. 1 claim. This is situated on the ridge summit at an elevation of 1,100 feet above Coal Creek, about half a mile north of the point where the creek flows through the Dakota sandstone ledges. In this and some other pits near by there was an apparent abundance of fossil wood, coated with bright-yellow pigment. This coating is very conspicuous and contrasts markedly with the dark iron-brown

[a] Bull. U. S. Geol. Survey No. 297, 1906.

rock on which it is found. Specimens from the Caywood No. 1 claim have been tested by George Steiger in the laboratory of the United States Geological Survey, and are reported by him as containing uranium and vanadium and as being probably carnotite. There is practically no doubt that the mineral is actually carnotite, as it has already been so determined by a number of authorities who have examined material from this locality. Material for a complete analysis has now been sent to the Survey laboratory and will probably be studied later.

The specimens collected were the better pieces among those lying out on the dump, together with some hammered from the ledges near their surface outcrop. The ore shows very clearly the original woody structure in the silicified gangue, which is now of a rusty-brown color and filled with seams and cracks. Some small pieces of coal were also found, but these were fragments or small patches and not a continuous seam. As is explained more fully on page 116, the yellow carnotite is evidently a surface coating, filling fractures and impregnating the neighboring sandstone.

A prospect pit said to be known as Caywood No. 2 is situated about 300 yards from Caywood No. 1 in a southerly direction along the ridge summit, but about 300 feet lower down. Here the sandstone showed a green stain for 4 or 5 feet down from the surface of the ledge on the ground, especially along the jointing planes in the rock. This prospect apparently contained no yellow ore, but a streak of fossil wood was exposed, embedded in the massive sandstone, which carried much green stain. This proved on testing[a] to be a copper stain and showed no trace of vanadium or uranium. The whole prospect pit was in massive though much broken sandstone. Below the Caywood No. 2 down the ridge to the bed of Coal Creek fragments of silicified wood were noted, apparently marking a single continuous stratum in the Dakota ledges.

OTHER PROSPECTS.

On the south side of Coal Creek, along the southerly continuation of the hogback ridge that has just been described, another prospect pit was found. This is about half a mile in a straight line south of Coal Creek and 1,200 feet or so above the main creek valley. No carnotite has been discovered here, but the silicified wood noted at the other prospects, as well as the associated strata, seemed at the time of visit to mark this pit as being at a horizon in the Dakota ledges almost, if not exactly, identical with that of the prospects already described. However, inasmuch as the plotting of this locality on the map seems to show its position as at some little distance west of the main sandstone ridge, the first conclusion as to its identity is

[a] By George Steiger, in laboratory of United States Geological Survey.

horizon with those to the north may not have been correct. West of the pit, down the hill slope, the outcrops of beds representing strata overlying the fossil-wood layer were noted as follows: Near the pit is a band of very red soil, thought to indicate a calcareous bed; beyond which a few feet of white granular sandstone or quartzite shows, dipping 40° W. Above this stratigraphically, although outcropping farther down the hillside, is a bed of conglomerate containing angular pebbles, many of which are limestone. Next is a bed of quartzite dipping 56° W., and then an interval of 100 feet or more of hill slope covered by vegetation and loose rock. Below this there is an outcrop of dark-green, compact, almost slaty shale, and scattered about in the soil are nodular masses of radial columnar calcite, ranging from a few inches in diameter to the size of a pumpkin, which some of them somewhat resemble in shape.

A little over a mile northeast of the Caywood No. 1 claim another prospect pit was found high up on the ridge, showing yellow carnotite ore in a mode of occurrence somewhat different from those already described. This prospect is near the top of a peak that was occupied in 1876 as a triangulation station by the topographic corps of the Hayden survey, who give its elevation as 9,430 feet. The pit itself is about 500 feet southeast of the summit and nearly as high. The ore seam lies 6 feet or so below the surface of the ground. The rock is the Dakota sandstone, much jointed and having a dip of about 20° a little west of north. Around this point the outcrop of Dakota ledges, together with the strata above and below, swings off toward the east, dipping in a northerly direction toward Thornburgh Mountain and Axial Basin and conforming in general with the anticlinal structure farther south, already noted in the section along the upper valley of Coal Creek. (See Pl. III.) The ore seen at this place is a seam an inch or so thick between two sandstone strata. The overlying bed is about 20 inches and that below about 4 inches thick. The ore seam itself is an irregular filling in what appears to be a stratification plane of the rock. This may possibly have been at one time the channel through which mineralized solutions have passed. The yellow pigment impregnates the inclosing sandstone on either side of the ore seam, producing sandy ore similar to that described from Montrose and San Miguel counties. No fossil wood was observed at this locality.

EXTENT AND ORIGIN OF THE DEPOSITS.

In view of the lack of development on the properties at the time they were visited little can be said as to the extent of these deposits in depth. By analogy with similar and better known deposits farther south in the same State it may be expected that these deposits will be found to be superficial in character. The occurrences seen had

the aspect of surface deposits, being mere coatings or films of an apparently secondary mineral in joints and fractures of the country rock, and this observation is corroborated by a closer examination of the ore itself. Under the microscope thin sections of material from the Caywood No. 1 claim show the cellular structure of the silicified wood, but no trace of impregnation with mineral within its mass, most of the carnotite with which the specimen had been coated having been lost in the grinding of the thin section. Evidently the silicification of the wood was fully completed before the carnotite was introduced. The hand specimen shows the same evidence, only the outer surface and coarser fractures of the comparatively impervious wood appearing to contain the yellow pigment.

It thus seems likely that carnotite is a surface or alteration product, representing in a secondary form some other original minerals from which its substance has been derived. As it has probably been deposited from solution in ground water it is very likely that the source of the rare elements which the deposits contain may have been at some considerable distance, and it is possible that the primary minèrals were widely disseminated in minute quantities, of which the present deposits are a product of concentration.

Doctor Hillebrand suggests in a personal communication that—

> Coal is a possible source of the vanadium and perhaps uranium in carnotite and other evidently secondary minerals that contain one or the other of these elements. This suggestion is based on the repeated finding of vanadium in coal ashes and the observation of uranium in anthracitic bitumen in Sweden and in nodular forms of carbon from the oldest sedimentaries of that country,[a] in grahamite from "North America,"[a] and in carbonaceous material from a pegmatite dike in Quebec.[b] Further, in the San Rafael Swell, in the eastern part of Utah, vanadium has been found by me in relatively large amount in the carbonaceous material accompanying and impregnating sandstone, and at Cerro de Pasco, Peru, carbonaceous matter very rich in vanadium occurs.[c] These facts are so indicative of a relation between vanadium and possibly uranium, and certain coals and carbonaceous materials that an examination of the coals and bitumens of western Colorado and eastern Utah for a possible content in these elements seems desirable. If found in them, the question of ultimate origin would still remain.

In this connection it may be pointed out that in all probability the coal seams formerly extended over and far beyond the position of the present uranium deposits; that these strata have since been removed by erosion; and also that the coal seams of the vicinity are at present largely burned along their outcrop. On the other hand, it seems that had these rare elements been derived from the coal seams we should now find traces of minerals containing these elements among the sandstones of the coal-bearing strata, rather than in deposits separated from the coal beds by a thickness of approximately a mile and a half

[a] Nordenskiöld, A. E., Comptes rendus, vol. 116, 1893, p. 677.

[b] Obalski, J., Jour. Canadian Min. Inst., vol. 7, 1904, p. 243; Eng. and Min. Jour., vol. 77, 1904, p. 441.

[c] Hewett, Foster, Eng. and Min. Jour., vol. 82, 1906, p. 385. Bravo, José J., Inform. y Mem. Bol. Soc. Ing. [Lima], vol. 8, 1906, p. 171.

of sedimentary rocks. No occurrences of carnotite have been observed or, so far as the writer knows, reported within the coal field itself. The only other suggestion that can now be offered to explain a possible source of uranium and vanadium is that they may have been derived from the basalt of Sleepy Cat Mountain, bowlders of which lie scattered over the Dakota sandstone ridges.

VALUE.[a]

In the absence of knowledge as to the nature and extent of the deposits in depth very little can be said of their probable commercial value. An announcement in the Engineering and Mining Journal of March 3, 1906, reporting the discovery of the properties that have been described in the foregoing pages, stated the intention of the owners to ship 10 tons of ore from these claims to Denver for treatment. It is not known whether this intention has been carried out or not, but to provide a sound basis for an estimate of values available the sample should represent more than the present shallow workings, and, as need hardly be stated here, should be a fair average of the actual run of prospecting that has been sufficiently extensive to warrant further commercial development in case the values are found satisfactory.

[a] An article in the Mining Magazine for February, 1906, describes a method of treating this ore in a commercial way.

NOTE ON A MINERAL PROSPECT IN MAINE.

By George Otis Smith.

Within the past few years there has been a revival of interest in mineral deposits in eastern Maine. In several localities where small copper, zinc, or lead mines were opened thirty years ago, the properties have been reexamined and in a few places shafts have been pumped out. At other places metalliferous veins have been prospected to determine whether the ore can be mined with profit under modern methods of ore treatment.

At the request of the Maine State Survey Commission the writer visited one of these prospects during the last season, and the following note is published, as it is believed that the deposit is somewhat typical of the disseminated sulphides of this region, so that the conclusions reached here may at least suggest the value of other similar deposits. The locality visited is in the town of West Pembroke on the farm of B. S. Sinclair, about a mile southeast of Ayers Junction on the Washington County Railroad. During 1906 considerable prospect work was done here, and shallow openings have been made at a dozen places on the hillside.

The country rock is metamorphic and of volcanic origin, much of it being a greenstone breccia with amygdaloid fragments. The bedding of the volcanic deposits appears to be represented by the sheets of varying texture, which have an east-west strike and steep dip. The rock is thoroughly silicified and more or less jointed.

The metalliferous minerals are sphalerite, galena, pyrite, and chalcopyrite, with quartz and calcite as gangue minerals. Oxidation has penetrated the rock for only 1 to 2 inches, and copper carbonates were seen at one place. These sulphides are scattered throughout irregular bands of the greenstone, the mineralized and unmineralized portions of the rock not being sharply contrasted. In no place is any well-defined vein exposed, although at one opening, No. 2, the more compact greenstone contains several small lenticular areas of quartz including small bunches of chalcopyrite. These cut across the sheeting of the rock. Where the breccia character of the greenstone is

well shown the sulphides occur more generally in the matrix, and in the amygdaloidal phases the metallic minerals are found in the amygdules.

A sample of ore was collected at the small opening designated the No. 6 prospect. Care was taken to procure a representative sample, with the view of determining the value of the material such as would necessarily be mined and shipped from a deposit of this type. Such selection was made to secure a good sample of the possible shipping product. The same quality of mineralized rock occurs at most of the openings, but at none could any commercial quantity of better grade ore be mined. On this account the sample is believed to be representative of this deposit and probably also to a large extent of other bodies of mineralized rock in this region.

The assay of this sample by Ledoux & Company of New York, follows:

Assay of ore from West Pembroke, Me.

Copper by electrolytic assay	per cent.	0.08
Zinc	do	1.26
Lead	do	.51
Silver (per ton 2,000 pounds)	ounce	.13
Gold (per ton 2,000 pounds)		Trace.

While this assay indicates a total content of between $2 and $3, under the present high prices of metals, the values are so distributed among the four metals that this valuation expresses little. No commercial process is known that would win all these metals, and with any treatment now in use the cost of the recovery of any two of them would doubtless exceed the value of the very small content in this rock. It can therefore be stated with confidence that the cost of mining and treating an ore of this type would be prohibitive.

NICKEL DEPOSITS OF NICKEL MOUNTAIN, OREGON.

By G. F. Kay.

INTRODUCTION.

For more than twenty-five years hydrated nickel magnesium silicates have been known to occur on Piney or Nickel Mountain near Riddles, in Douglas County, Oreg., and it has been hoped that development would prove the presence of these minerals in sufficient quantity for economic purposes. There seemed to be reason for this hope, since the deposits are in mineral content, in modes of occurrence, and in their associations very similar to the deposits of New Caledonia, whose mines are the second largest producers of nickel in the world. But as yet no commercial ores have been produced.

During the summer of 1906 Mr. J. S. Diller and the writer were engaged in mapping, for folio publication, the rocks of the Riddles quadrangle, in which the nickel silicates occur. In connection with this work, the writer made a special study of the ores, in order to get, if possible, a clearer idea of the modes of occurrence and the probable extent of these interesting deposits.

Thanks are due to Mr. W. Q. Brown, of Riddles, for kindness in the field and for information in regard to the development and other features of the ore bodies.

The literature on these deposits is as follows:

Clarke, F. W., Some nickel ores from Oregon: Am. Jour. Sci., 3d ser., vol. 35, 1888; pp. 483–488; Bull. U. S. Geol. Survey No. 60, 1890, pp. 21–26.

Analyses are given of the nickel silicates of the country rock (Saxonite), and of the olivine of the country rock. J. S. Diller gives the results of a microscopical study of the saxonite and of the ore. The evidence points to the saxonite as the source of the nickel.

Von Foullon, H. B., On Riddles, Oreg.: Jahrbuch K. k. geol. Reichsanstalt, vol. 42, Vienna, 1892, p. 223.

The minerals, their associations, and their probable origin are described. The ores are thought to have resulted from the decomposition, by superficial weathering, of the country rock, which he calls harzburgite. The processes of alteration are fully discussed.

Austin, W. L., The nickel deposits near Riddles, Oreg.: Proc. Colorado Sci. Soc., January, 6, 1896.

The location of the deposits, their method of occurrence, the development work, the probable origin of the ores, and the metallurgy of the ores, are fully discussed. The theory of deposition from ascending thermal waters is advanced.

Ledoux, A. R., Notes on the Oregon nickel prospects: Canadian Min. Rev., vol. 20, 1901, pp. 84–85; Jour. Canadian Min. Inst., vol. 4, 1901, pp. 184–189.

Describes the geologic relations of the ore bodies and gives a chemical analysis of the ore.

GEOGRAPHY AND HISTORY.

Nickel Mountain is one of many peaks and ridges of moderate elevation near the northeastern base of the Klamath Mountains in southwestern Oregon. It is about 3½ miles west of Riddles, a small village on the Southern Pacific Railroad, about 225 miles south of Portland. Riddles is 713 feet above sea level, and the highest point of Nickel Mountain is 3,513 feet above sea level. The nickel silicates are known to occur only on the southern slope of the mountain, above an elevation of 2,000 feet. A good wagon road about 7 miles in length runs from the village to a point within 200 feet of the summit of the mountain. All the important prospects are reached by this road.

Although these deposits were discovered about 1864, their true nature was not recognized until 1881. Soon after that time, under the management of W. Q. Brown, the original owner, development work was commenced, being continued in greater or less degree until 1900, when all work was suspended. Numerous surface openings were made, shafts sunk, and tunnels run. The longest tunnel, 320 feet in length, was completed in 1897 by the Oregon Nickel Mines Company. The deepest shaft, 83 feet deep, was sunk by the same company about the same time. In all, there are more than 600 feet of tunneling. Owing to the caving in of the walls, many of these workings are not now accessible except at the entrances. It is estimated that between 3,000 and 4,000 tons of material were taken from the various openings and placed on the dumps, where it still remains, much of it considerably leached and of low grade, the nickel minerals having been dissolved and carried away. Only a few small shipments of ore were ever made to the smelters, and these merely for experimental purposes. In 1893 the International Mining Company shipped considerable smelting machinery to Riddles, but it was never used. About the same time this company also erected, near the deposits, a brick engine and boiler house, a sawmill, a carpenter shop, a blacksmith shop, and other buildings, all of which are now in a more or less dilapidated condition.

GEOLOGY.

The nickel deposits are associated with saxonite or harzburgite, a variety of peridotite, a basic igneous rock consisting chiefly of olivine and enstatite. Olivine constitutes more than two-thirds of the whole

rock. Chromite and magnetite are in general present as disseminated grains, though in places within the peridotite area there are segregations of almost pure chromite. The peridotite readily breaks down to a dark-greenish serpentine, a rock that in the Nickel Mountain region is widely distributed as small isolated patches and elongated masses, the trend of which is northeast and southwest. Such an elongated mass of serpentine extends for several miles both to the northeast and to the southwest of Nickel Mountain. In some places the band is narrow; in others it is more than a mile in width. The serpentine has but a thin covering of soil, which is comparatively free from vegetation.

Other igneous rocks in this region are less basic than the peridotite and may be designated as greenstones and dacite porphyries. The greenstones comprise several types of rock, all of which are more or less dull green in color. They vary in texture from fine-grained and compact to coarsely granular. Most of them are considerably altered, but where fresh are usually found to consist essentially of pyroxene and soda-lime feldspars. The dacite porphyries are rather fine-grained, light-colored rocks and are much less abundant than the serpentines and greenstones. The chief minerals present are quartz and soda-lime feldspars, both of which in many places form distinct phenocrysts. Ferromagnesian minerals are subordinate.

The peridotite appears to have cut up through the greenstones, but was itself intruded by the dacite porphyries.

The sedimentary rocks are Mesozoic and Tertiary in age. The systems represented are Jurassic, Cretaceous, and Eocene. The Jurassic consists chiefly of sandstones and subordinately of shales, conglomerates, and cherts. The rocks as a rule show veining and pronounced lithification. Fossils are scarce, but the distinctly Jurassic form *Aucella erringtoni* has been found. The Cretaceous rocks consist chiefly of conglomerates, sandstones, and shales, and their fossils correspond to those of the Knoxville and Horsetown of California. There is evidence of a slight unconformity between the beds representing these two formations. The Knoxville rocks are lithified, but for the most part not nearly so strongly as the rocks of the Jurassic. The Eocene deposits consists of yellowish sandstone, shale, and conglomerate, the stratification of the rocks being well preserved.

A great unconformity can be traced between the Jurassic and the Cretaceous, and a somewhat less important unconformity separates the Cretaceous and the Eocene.

All the igneous rocks of the region are younger than the Jurassic, some are younger than the Cretaceous, and all are older than the Eocene.

THE ORE AND THE GANGUE.

Practically all the known occurrences of nickel silicate in this region are within an area of 1½ square miles, lying on the slopes to the south, southwest, and southeast of the mountain. The thin soil peculiar to this area is composed almost entirely of iron oxides, which give it a distinctly reddish-brown color. The ores occur chiefly as flat-lying deposits on the surface of the peridotite and subordinately as veinlets in the peridotite or its decomposition product, serpentine. Only one nickel mineral is known to occur in these deposits, namely, genthite, which is a soft hydrous nickel-magnesium silicate. The proportions of the nickel and magnesium vary considerably in the best specimens obtainable, as shown by the subjoined analyses:

Analyses of nickel silicates from Riddles, Oreg.

	1.	2.	3.	4.
Loss at 110° C	8.87	6.63	7.00	12.29
Loss on ignition	6.99			
$Al_2O_3+Fe_2O_3$	1.18	1.38	1.33	.06
SiO_2	44.73	48.21	40.55	48.82
MgO	10.56	19.90	21.70	18.49
NiO	27.57	23.88	29.66	19.04
	99.90	100.00	100.24	98.70

1. Clarke, F. W., Am. Jour. Sci., 3d ser., vol. 35, 1888, p. 484.
2–3. Hood, Dr., Mineral Resources U. S., 1882, U. S. Geol. Survey, 1883, p. 404.
4. Von Foullon, H. B., Jahrbuch K. k. geol. Reichsanstalt, vol. 42, 1892, p. 272.

There is probably every gradation from material with compositions like those of the foregoing analyses to pure silicate of magnesium. Von Foullon[a] states that he was able by washing to separate from the green ores of Nickel Mountain a light-colored material which on analysis proved to be magnesium silicate, containing no nickel. The color of the genthite varies with the nickel content from a pale green to a deep green—the more nickel present the more intense the color.

For the sake of comparison some analyses of the best nickel silicates of New Caledonia are given herewith:

Analyses of New Caledonia nickel silicates.[b]

	1.	2.	3.	4.	5.	6.	7.
H_2O	15.40	15.55	10.34	15.83	17.97	17.60	12.73
$Al_2O_3+Fe_2O_3$	.89	.50	1.68	1.57	.55	.11	3.00
SiO_2	42.61	35.45	44.40	37.78	38.35	37.49	47.90
MgO	18.27	2.47	3.45	10.66	10.61	14.97	12.51
FeO			.43				
CaO			1.07				
NiO	21.91	45.15	38.61	33.91	32.52	29.72	24.00
	99.08	99.12	99.98	99.75	100.00	99.89	100.14

[a] Jahrbuch K. k. geol. Reichsanstalt, vol. 42, 1892, p. 232.

[b] Annales des Mines, 10th ser., vol. 4, 1903, p. 368.

From all the analyses thus far published of the nickel silicates of New Caledonia and of Riddles it appears that the average content of nickel in the New Caledonia minerals is higher than that in the genthite of the Riddles deposits. Perhaps sufficient amounts of the Riddles ores have not been smelted to permit safe estimates to be made of their average nickel content; but the treatment by different methods of about 20 tons of the ore, which constituted the shipments made by the Oregon Nickel Mines Company, gave results varying from 5 to 8 per cent in nickel. Two specimens, taken by the writer as average samples of the ore, were analyzed in the Survey laboratory by George Steiger. The results were 5.35 and 4.94 per cent of nickel. Each of the two analyses also showed 0.11 per cent of cobalt. The New Caledonia ores now being shipped to the smelters contain between 6 and 7 per cent of nickel.

The gangue consists of quartz, iron oxides, and serpentine. The quartz, the most abundant of these minerals, is in general of a whitish color, but the surface of much of it has a yellowish to brownish-red tint, due to a coating of iron oxide. The quartz appears to be chiefly chalcedonic, but in places it has a weak greenish color, resembling chrysoprase, a mineral that has been shown to be present in these deposits.[a] The iron oxides are of a distinctly yellow to reddish-brown color, and the evidence is clear that these oxides represent one of the final products of decomposition of the serpentine, which is itself produced by the alteration of the peridotite.

THE DEPOSITS.

The deposits, which lie flat, occur as brecciated and conglomeratic irregular masses on the surface of the peridotite and consist of silica, nickel silicate, iron oxide, and serpentine, with a very subordinate amount of chromite. The most striking feature of the ore is the green color of the nickel silicate. Where the ores have been exposed to weathering action for a considerable time, these nickel silicates have been dissolved and carried away and a honeycombed quartz skeleton remains. In some of the cavities of this skeleton are found pulverulent iron oxides, which can readily be shaken out, only the siliceous cement of the former brecciated or conglomeratic mass being left. Such materials lie on the surface of a considerable part of the nickel area and have served as a guide to prospecting. A portion of this material has been transported mechanically to its present location. In some places the brecciated ore consists of irregular-shaped fragments of serpentine breaking down to hydrated iron oxides. The fragments are cemented by silica and nickel silicate, which were prob-

[a] Kunz, G. F., Gems and Precious Stones, p. 122.

ably deposited at about the same time. Here and there these cementing materials do not fill all the spaces between the fragments. In such places the cavities are lined with a thin film of silica having a mammillated surface. This thin film appears to have been deposited later than the general mass of cementing quartz and nickel silicate.

The distinctly conglomeratic ore differs from the brecciated ore in that the constituents are rounded rather than angular. This is particularly well shown by the nickel silicate itself, which consists of rounded concretions varying from the size of a pin's head to that of a walnut. When broken open, these are usually found to consist of homogeneous, apple-green, amorphous-looking nickel silicate, which on close inspection is seen to be penetrated by minute films of white silica; but in some of the ore the nickel silicate forms only a shell on the outside of the pebble, the inside consisting of decomposed serpentine or of brecciated ore, in which the small fragments of nickel silicate, iron oxide, and serpentine are plainly seen. Many specimens of the ore, both brecciated and conglomeratic, show slickensided surfaces, indicating movement subsequent to the formation of the ores.

The ore found beneath the flat-lying deposits occurs as small veins and minute veinlets in the peridotite, which contains innumerable fractures. These veins and veinlets run in various directions, forming an irregular network, but in the main they appear to be related to zones of fracture and brecciation that have a general northeast-southwest direction. These zones are of considerable width, but the individual fractures are narrow, the largest vein observed being not more than 6 inches wide and most of them less than 1 inch. The vein filling consists of nickel silicate and silica, but iron oxides are also present, and in some places the material is of the nature of a cemented breccia. Between the veinlets in the fractured zones the material is chiefly hydrated iron oxide in which rounded, bowlderlike masses of fairly fresh peridotite occur. In places the fractures are still unfilled, the walls being of peridotite but little altered.

Fault planes with slickensided surfaces were observed at several places within the nickel area. The relations of many of these fault planes to the ore bodies indicate that movements have taken place subsequent to the forming of the general mass of the ore.

ORIGIN OF THE ORES.

The field evidence strongly suggests that the nickel silicates are a decomposition product of the peridotite with which the ores are so intimately associated. The evidence derived from chemical analyses supports this view.

The nickel, which is by analysis found in small quantities in the fresh peridotite, appears to be associated with the constituent olivine

rather than with the enstatite. Clarke's analyses[a] of the rock and of the olivine are as follows:

Analyses of peridotite and olivine from Nickel Mountain, Oregon.

	Rock.	Olivine.		Rock.	Olivine.
Loss on ignition	4.41	0.57	NiO	0.10	0.26
SiO_2	41.43	42.81	MnO		
Al_2O_3	.04		CaO	.55	
Cr_2O_3	.76	.79	MgO	43.74	45.12
Fe_2O_3	2.52	2.61			
FeO	6.25	7.20		99.80	99.36

The rock analyzed was more than two-thirds olivine. The olivine analyzed was not entirely free from chromite and enstatite. Von Foullon analyzed the olivine of a peridotite from this region and found it to contain 0.32 per cent of nickel oxide; about 80 per cent of his rock was olivine. His analysis of the rhombic pyroxene of the peridotite gave only 0.05 per cent of nickel oxide.

Analyses of the serpentines which have been derived from the peridotite also show the presence of nickel. For example, Von Foullon states[b] that a specimen of serpentine taken near the border of the peridotite area contained 0.45 per cent of nickel oxide. A specimen taken by J. S. Diller from Iron Mountain, in the Port Orford quadrangle, more than 25 miles west of Nickel Mountain, yielded 0.13 per cent of nickel oxide.[c] A specimen obtained by the writer from a large serpentine area northeast of Nickel Mountain and analyzed by George Steiger showed 0.26 per cent of nickel, equivalent to 0.33 per cent of nickel oxide. Indeed, when we consider that the rocks containing nickel in small quantities are so widespread in this region, it is surprising that the deposits of nickel silicate appear so scanty. The writer has no definite evidence to account for the fact that the serpentines derived from the peridotite on the southern slope of Nickel Mountain are further decomposed into nickel silicate, silica, and iron oxide, whereas elsewhere they show no such alteration. It may be that the rocks in the vicinity of the deposits contained many more minute fractures and fissures than the rocks in other places. If so, weathering action must have been more effective and the decomposition of the rocks more complete near these deposits than where the fractures were fewer.

The field study of the nickel deposits and their associations reveals the various stages from the fresh peridotite to the final products of decomposition. The peridotite, under the ordinary atmospheric weathering processes, has been decomposed into serpentine, which in turn was further decomposed, the resulting products being hydrous

[a] Clarke, F. W., Am. Jour. Sci., 3d ser., vol. 35, 1888, p. 485.

[b] Jahrbuch K. k. geol. Reichsanstalt, vol. 42, 1892, p. 233.

[c] Geologic Atlas U. S., folio 89, U. S. Geol. Survey, 1903, p. 4.

ickel-magnesium silicate, silica, and iron oxides. The hydrous nickel-nagnesium silicate and silica were dissolved, carried out, and rede-osited in the cracks and crevices so abundant in the peridotite. 'he iron oxide, unless transported mechanically, remained behind in ne spaces formerly composed of peridotite or serpentine. It is robable that much of the material now found in the veins and vein-its in the peridotite has been leached from deposits formed higher p, carried down, and redeposited. Some material has probably been arried down mechanically.

This theory of origin is in accord with that advanced by Von Foul-on [a] after a careful study of the deposits. A similar view has recently een presented by Glasser [b] in explanation of the nickel-silicate eposits of New Caledonia.

If this theory is correct, the downward extension of the main eposits will be limited to the depth of decomposition of the peridotite.)n the other hand, if the theory of deposition by ascending thermal 'aters, as advanced by Austin, is correct, the deposits may extend ocally to greater depths, but of this there is no favoring evidence on ne surface. The depth of the deposit appears, fr'n present evi-ence, to be comparatively shallow.

[a] Jahrbuch K. k. geol. Reichsanstalt, vol. 42, 1892, pp. 224–233.

[b] Annales des Mines, 10th ser., vol. 4, 1904, pp. 448–464.

SURVEY PUBLICATIONS ON TIN, QUICKSILVER, PLATINUM, TUNGSTEN, CHROMIUM, AND NICKEL.

The principal publications by the United States Geological Survey on the metals here grouped are the following:

BECKER, G. F. Geology of the quicksilver deposits of the Pacific slope, with atlas. Monograph XIII. 486 pp. 1888.

——— Quicksilver ore deposits. In Mineral Resources U. S. for 1892, pp. 139–168. 1893.

BLAKE, W. P. Nickel; its ores, distribution, and metallurgy. In Mineral Resources U. S. for 1882, pp. 399–420. 1883.

——— Tin ores and deposits. In Mineral Resources U. S. for 1883–84, pp. 592–640. 1885.

CHRISTY, S. B. Quicksilver reduction at New Almaden [Cal.]. In Mineral Resources U. S. for 1883–84, pp. 503–536. 1885.

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EMMONS, S. F. Platinum in copper ores in Wyoming. In Bulletin No. 213, pp. 94–97. 1903.

GLENN, W. Chromic iron. In Seventeenth Ann. Rept., pt. 3, pp. 261–273. 1896.

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HESS, F. L., and GRATON, L. C. The occurrence and distribution of tin. In Bulletin No. 260, pp. 161–187. 1905.

HOBBS, W. H. The old tungsten mine at Trumbull, Conn. In Twenty-second Ann. Rept., pt. 2, pp. 7–22. 1902.

——— Tungsten mining at Trumbull, Conn. In Bulletin No. 213, p. 98. 1903.

KEMP, J. F. Geological relations and distribution of platinum and associated metals. Bulletin No. 193. 95 pp. 1902.

PACKARD, R. L. Genesis of nickel ores. In Mineral Resources U. S. for 1892, pp. 170–177. 1893.

RICHARDSON, G. B. Tin in the Franklin Mountains, Texas. In Bulletin No. 285, pp. 146–149. 1906.

ROLKER, C. M. The production of tin in various parts of the world. In Sixteenth Ann. Rept., pt. 3, pp. 458–538. 1895.

ULKE, T. Occurrence of tin ore in North Carolina and Virginia. In Mineral Resources U. S. for 1893, pp. 178–182. 1894.

WEED, W. H. The El Paso tin deposits [Texas]. Bulletin No. 178. 6 pp. 1901.

——— Tin deposits at El Paso, Tex. In Bulletin No. 213, pp. 99–102. 1903.

WEEKS, F. B. An occurrence of tungsten ore in eastern Nevada. In Twenty-first Ann. Rept., pt. 6, pp. 319–320. 1901.

——— Tungsten ore in eastern Nevada. In Bulletin No. 213, p. 103. 1903.

LEAD AND ZINC.

Many papers relating to silver-lead deposits will be found included in the list on pages 9 to 13 of this bulletin. The principal other papers on lead and zinc published by the United States Geological Survey or by members of its staff are the following:

ADAMS, G. I. Zinc and lead deposits of northern Arkansas. In Bulletin No. 213, pp. 187–196. 1903.

ADAMS, G. I., and others. Zinc and lead deposits of northern Arkansas. Professional Paper No. 24. 118 pp. 1904.

BAIN, H. F. Lead and zinc deposits of Illinois. In Bulletin No. 225, pp. 202–207. 1904.

——— Lead and zinc resources of the United States. In Bulletin No. 260, pp. 251–273. 1905.

——— A Nevada zinc deposit. In Bulletin No. 285, pp. 166–169. 1906.

——— Zinc and lead deposits of the upper Mississippi Valley. Bulletin No. 294. 155 pp.

BAIN, H. F., VAN HISE, C. R., and ADAMS, G. I. Preliminary report on the lead and zinc deposits of the Ozark region [Mo.-Ark.]. In Twenty-second Ann. Rept., pt. 2, pp. 23–228. 1902.

CLERC, F. L. The mining and metallurgy of lead and zinc in the United States. In Mineral Resources U. S. for 1882, pp. 358–386. 1883.

ELLIS, E. E. Zinc and lead mines near Dodgeville, Wis. In Bulletin No. 260, pp. 311–315. 1905.

GRANT, U. S. Zinc and lead deposits of southwestern Wisconsin. In Bulletin No. 260, pp. 304–310. 1905.

HOFFMAN, H. O. Recent improvements in desilverizing lead in the United States. In Mineral Resources U. S. for 1883–84, pp. 462–473. 1885.

ILES, M. W. Lead slags. In Mineral Resources U. S. for 1883–84, pp. 440–462. 1885.

KEITH, A. Recent zinc mining in East Tennessee. In Bulletin No. 225, pp. 208–213. 1904.

RANSOME, F. L. Ore deposits of the Coeur d'Alene district, Idaho. In Bulletin No. 260, pp. 274–303. 1905.

SMITH, W. S. T. Lead and zinc deposits of the Joplin district, Missouri-Kansas. In Bulletin No. 213, pp. 197–204. 1903.

ULRICH, E. O., and SMITH, W. S. T. Lead, zinc, and fluorspar deposits of western Kentucky. In Bulletin No. 213, pp. 205–213. 1903. Professional Paper No. 36. 218 pp. 1905.

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WINSLOW, A. The disseminated lead ores of southeastern Missouri. Bulletin No. 132. 31 pp. 1896.

WOLFF, J. E. Zinc and manganese deposits of Franklin Furnace, N. J. In Bulletin No. 213, pp. 214–217. 1903.

IRON AND MANGANESE ORES.

THE CLINTON OR RED ORES OF THE BIRMINGHAM DISTRICT, ALABAMA.

By Ernest F. Burchard.

INTRODUCTION.

Detailed work on the iron ores of the Birmingham district was carried on in the summer of 1906, continuing to the southward the studies of these ores begun in northeast Alabama by E. C. Eckel in the fall of 1905.

By the Birmingham district is meant the area from which the furnaces at Birmingham, Ensley, and Bessemer derive their iron ores. It is comprised within the southeastern part of the Birmingham 30-minute quadrangle, the northwest quarter of the Bessemer quadrangle, and the northeast quarter of the Brookwood quadrangle. As a complete report, with maps, covering the iron ores and iron industry of the Birmingham district, is now in preparation, this paper presents only an outline of the principal facts regarding the red ore that were noted in the course of the survey. The brown ores used in the district come mainly from the vicinity of Woodstock. These ores, together with their geologic relations and extent, have been described in a previous Survey report.[a] The present bulletin contains an article by Charles Butts (pp. 247-255), outlining the distribution and character of the local fluxing materials.

THE TOPOGRAPHY AND ITS RELATIONS TO INDUSTRIAL DEVELOPMENT.

The city of Birmingham and its suburbs are built in the heart of the valley region of Alabama. This valley region lies between the Cahaba coal field on the southeast and the Warrior coal field on the northwest, and its rectilinear ridge and valley type of topography is in

[a] Burchard, E. F., Iron ores in the Brookwood quadrangle, Alabama: Bull. U. S. Geol. Survey No. 260, 1905, pp. 321-334.

strong contrast with the irregular, roughly dissected topography of the coal fields.

The valley topography is characterized by long, narrow, canoe-shaped troughs, in general parallel to each other and separated by well-defined ridges. The trend of the valleys is approximately N. 30° E. Their form is directly dependent on the geologic structure and lithology of the underlying rocks. They are developed mainly on the softest and most soluble rocks, along the axes of anticlines, the most enduring strata on the limbs of the folds forming the rims of the valleys. At distances of 2 to 5 miles apart openings or "gaps," some of which extend to the valley level, are cut at right angles through the ridges and afford convenient passageways between the valleys.

Birmingham Valley, the largest and from an industrial standpoint the most important of these valleys, extends from the vicinity of Springville on the northeast beyond Vance on the southwest, and from the Warrior coal field, or Sand Mountain, on the northwest to the Cahaba coal field, or Shades Mountain, on the southeast. To the southwest the inclosing ridges pass below unconsolidated Cretaceous and Tertiary clays and sands; to the northeast lies Blount Mountain. Birmingham Valley thus has a length of nearly 75 miles, an average width of more than 6 miles, and an area of nearly 500 square miles. This valley is divided into minor valleys by low ridges, such as Red Mountain and West Red Mountain, Flint Ridge, and Cemetery Ridge, all due to folding and faulting of the main anticline; and this complicated structure finds expression in Shades and Roups valleys at the southeast and southwest ends and in Jones and Opossum valleys at the northeast and northwest ends, respectively. This system of valleys varies in the altitude of its lowest levels from about 400 feet at the southwest to 700 feet at the northeast end. These altitudes are higher than the lowest levels cut by streams in the dissected plateau country, and consequently streams do not flow lengthwise through the valleys, but after flowing a short distance break through the bordering ridges and flow out into the lower country beyond. Birmingham Valley, on account of its relatively high altitude, really forms a divide, since its northwestern portion is drained by Warrior River and its southeastern portion by Cahaba River.

Red Mountain, the main minor ridge within Birmingham Valley, furnishes nearly all the red ore smelted in the district, and the Woodstock area, in the southwestern portion of the valley, produces the major part of the brown ore. Coking coal is mined in the Warrior coal field, only a few miles distant from the furnaces. Dolomite and limestone, suitable for fluxing, occur in the valley rocks below and above the red ore. Only in the southern Appalachian iron-ore districts is there grouped this series of deposits, each

member of which is more or less dependent on the others, but which taken together form such a matchless combination of raw materials. The simple, regular topographic features of the valley have made accessible the ores and stone at every point where they are of workable character, and enterprising railroad companies have rapidly improved the opportunities for developing the region. The only serious problem involved by the valley topography is that of obtaining a water supply adequate for manufacturing purposes. The relatively high altitude of the valley, as before stated, has diverted the streams that rise within its borders. The supply from large springs is now nearly all utilized as soon as it emerges from the ground, but this is not sufficient to meet the demands. The Birmingham city supply is piped from the distant Cahaba River, and some of this water is used by manufactories, although its cost in large quantities is necessarily almost prohibitive. Two courses are open to the manufacturers—first, that of forming an association and building another large aqueduct from Cahaba River and, second, that of sinking deep wells at the several plants. The first plan involves cooperation and its results are assured. The second plan can be carried out by individual firms, but it would be an expensive experiment.

GEOLOGY.

STRATIGRAPHY.

The rocks underlying Birmingham Valley and constituting its borders may be grouped in the following section:

Section of Paleozoic rocks in Birmingham Valley.

System.	Formation.	Thickness.
		Feet.
Carboniferous	Massive very hard sandstone, somewhat pebbly	100–600
	Interbedded shale and sandstone	100–2,200
	Bangor limestone	0–300
	"Oxmoor" sandstone and shale	50–300
	Fort Payne chert	200–[illegible]
Devonian	Chattanooga shale	0–20
Silurian	Rockwood (Clinton) shale, sandstone, and iron ore	180–300
Ordovician	Chickamauga ("Trenton") limestone	200–800
Cambro-Ordovician	Knox magnesian limestone and chert	2,000–2,700
	Knox dolomite	500–600
Cambrian	Conasauga shale and limestone	[a] 1,500

[a] Base not exposed.

The base of the Cambrian system is not exposed in this area, and the rocks above the massive sandstone may be considered as belonging to the coal measures and consequently outside of the iron-ore district.

STRUCTURE AND DISTRIBUTION OF FORMATIONS.

A very much generalized section beginning at the Cahaba coal field on the southeast and passing northwestward across the valley at Birmingham would expose the rocks in the order of the above table, reading from the top down, with varying dips on the southeastern flank of a nonsymmetrical anticline having the Conasauga shale and limestone on the axis of the fold. A minor syncline follows, faulted down to the southeast, with the Knox formation held in the basin. The Conasauga again appears to the northwest of the Knox syncline, and bordering the Conasauga, on the northwest side of the valley, is an extensive overthrust fault which brings the Lookout sandstone and coal measures in contact with Cambrian and Ordovician rocks. For a short distance northwest of the fault the rocks show steep reversed or southeasterly dips, so that the only northwesterly dips displayed in the section are in connection with the small syncline of Knox chert and dolomite within the valley.

Here and there along the overthrust fault the throw has not been great enough to engulf the Silurian rocks completely, and at such places the Rockwood formation, dipping steeply, is exposed in a narrow outcrop. The presence of this formation in places on the northwest side of the valley has given to the ridge the name West Red Mountain. In the section outlined above, the Rockwood sandstone forms the crest of Red Mountain, with the Fort Payne chert overlying it and the Chickamauga limestone underlying it, making, respectively, the southeast and northwest slopes of the mountain. All the formations may be considered to extend longitudinally throughout the valley, in practically the relationships already indicated. The minor folding and faulting has duplicated the strata of West Red Mountain in the southern part of the valley, forming McAshan Mountain and a low ridge partly buried by post-Paleozoic sediments, south of Dudley. At the northeast end of the valley the extent of outcrop of the Rockwood and associated strata is increased by the synclinal Blount Mountain with the outlying Cedar Mountains, and by the synclinal structure north of Trussville.

Red ore occurs in practically all the outcrop areas of the Rockwood formation, but only in Red Mountain has it been found of sufficient thickness and purity to be worked on an important scale. The workability of the ore depends largely on the attitude of the inclosing strata. The beds of Red Mountain dip southeastward at moderate angles, which are in the main fairly constant for a mile or more along the strike and for a quarter to half a mile down the dip. Locally there are abrupt "rolls" or changes in the dip due to minor folds parallel to the main axis, and in some places the ore has been so faulted that efforts to find it or to exploit it further have been suspended.

The questions of deepest importance to the district are (1) whether the present quality of the ore will be maintained to great depth, (2) whether the present workable thickness will continue to whatever depth it may be possible to mine the ore, and (3) whether the structure of the rocks underlying Shades Valley—below which the ore beds normally lie—will be favorable for mining the ore. Certain facts have been brought out during this survey which have a bearing on these questions. These will be noted and discussed in the complete paper, but the nature of the present paper precludes more than a reference to the general conclusions.

CHARACTER OF THE ORES.

The ores consist essentially of red hematite, intimately mixed with varying percentages of lime and silica. The hematite occurs in beds interstratified with shale and sandstone, and the strata mostly dip at angles varying from 10° to 50°. In places, more particularly to the north of the Birmingham district, the Clinton ore is oolitic. Through-out its extent some beds are very fossiliferous, and some of the fauna found in the Birmingham district are typical Clinton forms of the New York section. Near Birmingham the ore beds are largely com-posed of fine to coarse silica pebbles, coated and cemented with ferric oxide. According as the ore is high or low in lime it is terme "hard" or "soft" ore. The distinction between the two varieties i based on differences in their chemical composition rather than o differences in hardness, although the terms "hard" and "soft" a originally applied to the ores probably had reference to their physica condition, since on the outcrop the soft ore is in general rather porou and friable. The unaltered ore is of the hard variety. The soft or has resulted from the leaching by percolating waters of the soluble lim carbonate contained in the hard ore. This alteration occurs at th outcrop of the ore beds and down the dip to varying distances, depend ing on the thickness and permeability of the cover. Where the strat dip at fairly high angles and are underlain by impervious shale, th conditions are favorable for the passage of water through the beds t considerable depths. In a few places pockets of soft ore, surrounde by unleached ore, are encountered at relatively long distances from th outcrop. Such an occurrence of soft ore is usually due to the presenc of fissures or brecciated rock, through which surface water has reache the ore bed. Where the overlying cover is heavy at the mouth of a slope or tunnel, the soft ore rarely extends more than 50 feet, but he and there the ore has been well leached to a distance of 400 feet fro the outcrop. With the removal of the lime carbonate from the ori inal ore the relative percentages of the remaining less soluble consti uents, mainly iron oxide and silica, are increased. The followi

analyses show at the left a typical hard ore and at the right a typical soft ore, with intermediate or semihard grades between them:

Analyses of Clinton iron ores, showing gradation from hard to soft ore.

	1.	2.	3.	4.
Iron, metallic (Fe)	37.00	45.70	50.44	54.70
Silica (SiO_2)	7.14	12.76	12.10	13.70
Alumina (Al_2O_3)	3.81	4.74	6.06	5.66
Lime (CaO)	19.20	8.70	4.65	.50
Manganese (Mn)	.23	.19	.21	.23
Sulphur (S)	.08	.08	.07	.08
Phosphorus (P)	.30	.49	.46	.10

These analyses represent ore samples from a single slope on the same horizon of the Big seam in Red Mountain, near Birmingham, at distances respectively of 540, 480, 420, and 240 feet from the mouth of the slope. Beyond the point at which No. 1 occurs there is no great change in the character of the ore, for, as mined at present, the seam carries an average of 35 per cent metallic iron in this particular mine.

Although the soft ore carries a higher percentage of iron, the hard ore has the advantage of containing almost or, in places, quite enough lime to flux the silica that it contains. In case a hard ore contains more lime than is needed to flux its silica soft ore or brown ore (limonite) may be added to the burden to take up the excess of lime.

RELATIONS AND CHARACTER OF THE ORE BEDS.

The Rockwood formation, in which the ores occur, is extremely variable in thickness and in the details of its stratigraphy, although the presence of beds of hematite somewhere within the formation is a remarkably persistent feature, not only throughout the length of the Appalachians, but in rocks of equivalent age in Wisconsin and New Brunswick. In Alabama the formation is thickest at the north and there contains beds of limestone, which give way to sandstone with the thinning of the formation toward the south; the proportion of shale in the Rockwood is also greatest in the northern part of the State.

DESCRIPTION OF THE ORE-BEARING FORMATION.

BEDS ON RED MOUNTAIN.

Within the district here considered the Rockwood formation shows notable variations in composition from northeast to southwest, as is indicated by the following seven sections on Red Mountain, beginning northeast of Birmingham and continuing at irregular intervals for about 38 miles to the southwest. In each section the observed thickness has been corrected for the dips, which range between 20° and 50°, so that the computed thickness closely represents the actual thickness of the beds.

1. *Section of Rockwood formation in NE. ¼ sec. 23, T. 17 S., R. 2 W., near Irondale.*

	Ft.	in.
Top of formation unexposed.		
Sandstone, yellowish, heavy bedded	40	0
Unexposed	11	9
Sandstone	4	7
Unexposed (probably in large part shale)	19	10
Sandstone, green, flaggy, with yellow shale partings	25	0
Iron ore (*Ida seam*)	5	0
Shale, red		2
Sandstone, ferruginous, laminated	1	8
Iron ore (*Big seam*): Ore, sandy	1	8
Iron ore (*Big seam*): Ore, lean, filled with small quartz pebbles	5	0
Iron ore (*Big seam*): Ore, minable	7	0
Iron ore (*Big seam*): Ore, fair quality, but not mined at present	6	0
Iron ore (*Big seam*): Ferruginous sandstone, ore, and shale, in layers 1 foot or less thick	20	0
Sandstone, very hard	3	0
"Gouge," calcareous		6
Iron ore (*Irondale seam*)	5	6
Sandstone, brown, thin bedded, with shale	20	0
Unexposed (probably shale)	65	0
Limestone (Chickamauga).		
	241	8

2. *Generalized section of Rockwood formation in SW. ¼ sec. 23, T. 17 S., R. 2 W., jus south of Red Gap.*

	Ft.	in.
Chert (Fort Payne).		
Shale (may include a few inches Devonian)	11	0
Sandstone, coarse, ferruginous	25	0
Iron ore, solid (*Ida seam*)	6	0
Sandstone, coarse, ferruginous	25	0
Sandstone, coarse, pebbly; partially a low-grade ore	22	0
Shale		1
Iron ore (*Big seam*): Upper part, minable	7	0
Iron ore (*Big seam*): Lower part, not yet mined	10	0
Shale	3	
Iron ore (*Irondale seam*)	4	4
Sandstone, red, soft	30	0
Sandstone, brown	35	0
	178	5

3. *Section of Rockwood formation on road across Red Mountain, in NW. ¼ sec. 5, T. 1 S., R. 2 W.*

	Ft.	in.
Chert (Fort Payne).		
Sandstone, heavy bedded	8	0
Unexposed	6	8
Sandstone, medium bedded	6	9
Unexposed	6	8
Shale	5	5

	Ft.	in.
Unexposed	53	0
Iron ore, sandy (*Hickory Nut* (?) *seam*)	3	9
Unexposed	7	6
Sandstone, coarse, very ferruginous, thin bed	2	3
Sandstone, fine grained, very ferruginous, thin bed		9
Sandstone, coarse, ferruginous, with beds of ore (*Ida seam*)	10	3
Sandstone, medium bedded, coarse	40	6
Unexposed	3	9
Shale	7	0
Unexposed	3	9
Sandstone, heavy bed	2	5
Iron ore, coarsely siliceous (*Big seam*); top 10 feet minable	16	10
Sandstone	7	8
Iron ore (*Irondale seam*): Ore	1	0
Iron ore (*Irondale seam*): Shale		7
Iron ore (*Irondale seam*): Ore	1	1
Sandstone	1	0
Unexposed, covered by shaly sandstone débris	50	1
Sandstone, massive, with shaly partings	24	1
Sandstone, thin bed	5	7
Unexposed	4	6
Sandstone, thin bed	5	6
Unexposed	4	6
Sandstone, thin bed	3	7
Unexposed	7	6
Sandstone, thin bed	3	7
Unexposed	5	8
Shale, sandy	7	6
Unexposed, covered by red shaly sandstone débris	35	10
Limestone (Chickamauga).		
	331	0

4. *Section of Rockwood formation in Walker Gap, in NE. ¼ sec. 14, T. 18 S., R. 3 W.*

	Ft.	in.
Chert (Fort Payne).		
Shale, clay, and sand (Devonian)	3	10
Sandstone, massive	16	10
Sandstone and shale	13	7
Shale, drab to pink, with thin streaks of sandstone (partly concealed by débris)	85	4
Sandstone and shale, alternating	50	9
Iron ore (*Big seam*), top 8 to 15 feet minable	24	0
Sandstone and shale, with ore seams in upper part	13	7
Débris	50	10
Shale, yellow, red, and olive, with heavy sandstones interbedded	41	0
Sandstone, heavy bedded	3	5
Shale, yellow and red	37	4
Base not exposed, but within distance of 20 feet	20	0
	360	6

5. *Section of Rockwood formation in Tanyard Gap, in SE. ¼ sec. 2, T. 19 S., R. 4 W.*

		Ft.	in.
Chert (Fort Payne).			
Shale (Chattanooga), (less than 1 foot).			
Sandstone, thin bedded		12	2
Unexposed		10	10
Sandstone, dark red, heavy bedded		8	9
Unexposed		11	3
Sandstone, red, heavy bedded		4	8
Unexposed		7	8
Sandstone, red, medium bedded		3	10
Sandstone, very ferruginous, with casts of *Pentamerus* (*Hickory Nut ore seam*)		3	0
Sandstone, red, ferruginous, thin bedded		2	4
Unexposed		16	4
Sandstone, heavy bedded		2	4
Iron ore (*Ida seam*); soft ore, minable		3	0
Sandstone, heavy bedded		3	0
Unexposed		15	4
Sandstone, medium bedded		20	2
Iron ore (*Big seam*)	Ore, minable	11	0
	Shale	2	6
	Ore, not minable	4	6
	Shale, sandy, with thin ore seams, not minable	3	0
Sandstone, thin bedded		2	4
Shale		11	3
Sandstone		1	6
Shale		2	8
Unexposed		3	9
Shale, sandy		56	0
Covered by shale débris		12	6
Limestone (Chickamauga).			
		235	8

6. *Section of upper part of Rockwood formation as shown by core from diamond drill, NE. ¼ SW. ¼ sec. 11, T. 19 S., R. 4 W.*

	Ft.	in.
Chert, solidly stratified (Fort Payne).		
Sandstone, red, with coarse grit	5	8
Grit, coarse, soft, with gray sandstone	5	8
Limestone, gray, hard, cherty	6	7
Limestone, ferruginous	31	0
Sandstone, ferruginous	2	7
Sandstone, gray, extremely hard in places	23	6
Sandstone, ferruginous	40	7
Grit, very hard, fine, with reddish sandstone	20	2
Iron ore, limy (*Ida seam* (?))	2	7
Sandstone, gray	7	11
Limestone, "marbleized"	15	0
Sandstone, gray, hard	1	11
Limestone, ferruginous	5	8
Sandstone, ferruginous	22	0

		Ft.	in.
Iron ore (*Big seam*); top 11 feet minable	Ore	11	1
	Sandstone, gray	2	5
	Shale, ferruginous		8
	Ore, limy	2	5
	Sandstone, highly ferruginous	4	8
	Sandstone, mottled, highly ferruginous and fossiliferous	1	3
Calcareous rock, gray, with sandstone and shale interstratified		30	0
Bottom of formation probably within 35 feet.			
		246	4

Section of Rockwood formation as shown by core from diamond drill at Big Spring, in SE. ¼ SE. ¼ sec. 34, T. 21 S., R. 6 W.

		Ft.	in.
Limestone, decomposed (Fort Payne).			
Limestone, hard		2	1
Sandstone, reddish		35	0
Limestone (?), impure, with shale streak		27	9
Ferruginous rock, red, mottled		2	3
Limestone (?), with mottled red streaks, and shale		25	6
Limestone (?), gray, "marbleized"		1	11
Limestone (?), gray, "marbleized," fossiliferous		8	2
Limestone (?), gray, "marbleized," with liver-colored spots		7	6
Limestone and shale alternating		16	0
Sandstone, dark brown		2	6
Sandstone, laminated, ferruginous		29	0
Shale, gray, sandy		32	10
Ferruginous rock, streaked		26	3
Iron ore (horizon of *Big seam*)	Ore, soft, no core	3	9
	Sand, highly ferruginous, no core	4	10
	Ore, lean, with shale streaks	1	11
Iron ore, fossiliferous		3	7
Limestone (?), gray, impure, streaked with flint		48	8
Sandstone, red streaked		5	0
Limestone, with hard black flint (Chickamauga).			
		284	6

The foregoing sections show, besides the variation in details of the rmation, the relations of the several ore beds. Four beds have been cognized and named by the miners. These are all shown in section but in the other sections one or more of them have not been recog-zed. The following summary shows the salient features of these e beds, commencing with the uppermost:

DESCRIPTION OF THE ORE SEAMS.

Hickory Nut seam.—This seam comprises 3 to 5 feet of sandy ore ferruginous sandstone characterized by a great abundance of *entamerus oblongus,* fossils which resemble hickory nuts incased in

the partly open outer shucks. The ore is of too low grade to be worked at present. The seam is developed principally in the district between Birmingham and Bessemer, and where recognized it lies about 12 to 20 feet above the next lower seam.

Ida seam.—This seam consists of 2 to 6 feet of rather siliceous ore associated with 14 to 16 feet of ferruginous sandstone. Ore at this horizon is more continuous and extensive than at the horizon of the Hickory Nut seam. It has been recognized at many of the workings from Bald Eagle Gap beyond Clear Branch Gap. Where worked the seam is in general from 3 to 5 feet thick and soft ore only has been obtained from it in surface workings. Such ore carries 35 to 44 per cent of metallic iron, with a corresponding range in silica of 45 to 32 per cent. The Ida seam occurs 35 to 50 feet above the top of the Big seam.

Big and Irondale seams.—These two ore beds are considered together since they are very closely associated in space. The ore, however, is somewhat different in quality, and the seams are so sharply separated by thin sandstone or shale that they may be mined independently.

The thickness of the Big seam is variously estimated at 16 to 40 feet. It extends as a traceable unit on Red Mountain practically the whole length of the mining district. Notwithstanding the great thickness there are rarely more than 10 to 12 feet of good ore in a single bench, and at most places only 7 to 10 feet are mined. Probably the maximum thickness is attained between Red Gap (near Irondale) and Bald Eagle, although for a mile southwest of Red Gap the bed remains nearly as thick. From northeast to southwest the total thickness of the ore-bearing sediments gradually decreases, without, however, altering greatly the thickness of the workable portion. About the middle of the district the seam becomes separated into two benches, either by a well-defined parting along the bedding plane or by a shale bed, thin at first, but thickening gradually to the southwest. The middle of the Big seam is the workable part in the northeast end of the district, but the upper bench is of most importance throughout the rest of the area. In the southwest portion of the district the lower bench, which farther northeast is composed of ore that will in later years be mined, becomes a series of thin strata of lean ore and shale, and is consequently of no possible value; and finally the upper bench itself becomes shaly and carries only a very low-grade ore.

The Irondale seam is best developed on Red Mountain between Pilot Knob on the northeast and Lone Pine Gap on the southwest. Southwest of Lone Pine Gap the seam either consists of interbedded low-grade iron ore and shale or else its identity is completely lost. Its soft ore, now nearly all mined out either by surface trenches or

slopes, is the best in the district. Its hard ore is also of high grade and hitherto has been for the most part held in reserve, since ore could be produced from the thicker Big seam at a lower cost per unit of iron.

The structure and composition of the Big and Irondale seams is shown in the following series of sections, taken at intervals of 2 to 5 miles apart along Red Mountain, beginning in the northeast portion of the mining district:

Character of Big and Irondale seams 1 mile northeast of Red Gap, near Irondale.

Strata.	Thickness.	Character.
	Ft. in.	
Sandstone.		
Big seam:		
Ore, sandy	1 8	Metallic iron, 16–20 per cent; insoluble, 40± per cent; lime, 18± per cent.
Ore, lean, with fine quartz pebbles	5 0	
Ore, massive, cross bedded, mined	7 0	Hard ore, averages metallic iron, 36 per cent; insoluble, 26 per cent; lime, 20 per cent.
Ore, similar in appearance to above, but not mined at present.	6 0	Percentage of iron grades down from 35 at top to less than 20 at bottom; insoluble rises to more than 60 per cent.
Sandstone, ferruginous, lean ore, and shale.	20 0	
Shale	0-6	
Sandstone, very hard	3 0	
"Gouge," calcareous	6	
Irondale seam:		
Ore, mined	5 0	Semihard ore, averages metallic iron, 37 per cent; insoluble, 29 per cent; lime carbonate, 14.25 per cent.
Shale, hard.		

Character of Big and Irondale seams one-half mile south of Red Gap.

Strata.	Thickness.	Character.
	Ft. in.	
Sandstone, coarse, ferruginous.		
Big seam:		
Ore, containing much silica in coarse grains and fine pebbles.	22 0	Upper half, soft ore: Metallic iron, 22± per cent; insoluble, 64± per cent; lime, trace. Lower half, soft ore: Metallic iron, 32± per cent; insoluble, 47± per cent; lime, trace.
Shale	1	
Ore, mined	7 0	Soft ore: Metallic iron, 36± per cent; insoluble, 45± per cent; lime, trace.
Ore, not mined	10 0	Semihard ore: Metallic iron, 25± per cent; insoluble, 50± per cent; lime carbonate, 8.12 per cent.
Shale soft	3 0	
Irondale seam:		
Ore, mined	4 4	Soft ore: Metallic iron, 50± per cent; insoluble, 15± per cent; lime, trace.

The two following sections, made within the next 5 miles to the southwest, show that although the total thickness of the iron-bearing strata in this direction grows gradually less, yet the thickness of workable material remains fairly constant.

Character of Big and Irondale seams near Lake View, Birmingham.

Strata.	Thickness.	Character.
	Ft. in.	
Sandstone, thin bedded.		
Big seam:		
Ore, mined	10 0	Soft ore: Metallic iron, 40± per cent; insoluble, 39± per cent; lime, trace. Hard ore: Metallic iron, 31± per cent; insoluble, 26± per cent; lime, 20± per cent.
Shale	8	
Ore, not mined	7 0	Value decreases regularly downward. Soft ore: Metallic iron, 15 to 25 per cent; insoluble, 50 to 60 per cent.
Shale	2 0	
Irondale seam:		
Ore	2 8	Hard ore: Metallic iron, 38± per cent; insoluble, 16± per cent; lime carbonate, 21± per cent. Soft ore: Metallic iron, 47± per cent; insoluble, 26± per cent. Only hard ore mined at present.
Shale	9	
Ore	2 2	

Character of Big and Irondale seams near Lone Pine Gap.

Strata.	Thickness.	Character.
	Ft. in.	
Shale.		
Big seam:		
Ore, mined	10± 0	Hard ore: Metallic iron, 36± per cent; insoluble, 25± per cent, lime carbonate, 20± per cent. Soft ore: Metallic iron, 41± per cent; insoluble, 35± per cent. Semihard ore mined at present.
Shale	1±	
Ore, not mined	6 6	Deteriorates in value regularly downward, top ore being poorer than the ore mined above.
Shale	2 0	
Irondale seam:		
Ore, not mined	6 0	Low-grade ore interbedded with shale.

The following section illustrates the complete deterioration of the Irondale seam:

Character of Big and Irondale seams at open cut, Greenspring mine, SW. ¼ sec. 11, T. 9 N., R. 3 W.

Strata.	Thickness.	Character.
	Ft. in.	
Sandstone, coarse, ferruginous.		
Shale, yellow.		
Big seam:		
Ore, massive, cross-bedded and jointed; mined.	8 0	Soft ore: Metallic iron, 42± per cent; insoluble, 31± per cent; lime, 2± per cent. Semihard ore: Metallic iron, 38± per cent; insoluble, 32± per cent; lime, 8± per cent. Mostly semihard ore mined at present.
Parting on bedding plane.		
Ore, rather a ferruginous sandstone or coarse grit; mined in only a few places.	8 0	
Shale	2	
Sandstone, ferruginous and shaly	1 0	
Shale, sandy	6	
Sandstone, ferruginous	1 3	

Character of Big and Irondale seams at open cut, Greenspring mine SW. ¼ sec. 11, T. 9, N., R. 3 W.—Continued.

Strata.	Thickness.	Character.
	Ft. in.	
Shale	2	
Sandstone	4	
Shale	2	
Ore, sandy	5	
Shale	5	
Ore, sandy	3	
Shale	2	
Irondale (?) seam:		
Ore, very sandy	1 6	Not minable.
Shale	2	
Sandstone, fine grained, very ferruginous.	1 4	
Shale	2	
Sandstone, fine grained, very ferruginous.	10	
Shale	1	
Sandstone, very ferruginous	5	
Shale	1	
Sandstone, very ferruginous	10	
Shale.		

At Graces Gap only the Big seam appears to be present. It has a thickness of about 22 feet here, and the upper bench, 10 to 12 feet of ore, is mined. Four miles southwest of the locality of the foregoing section the ore presents the following phase:

Character of Big and Irondale seams at mouth of slope No. 12, Tennessee Coal, Iron and Railroad Company, SE. ¼ sec. 20, T. 18 S., R. 3 W.

Strata.	Thickness.	Character.
	Ft. in.	
Shale and sandstone in thin beds.		
Big seam:		
Ore, mined	8-10 0	Hard ore: Metallic iron, 35± per cent; insoluble, 18± per cent; lime, 16± per cent. Only hard ore mined now.
Shale, thin parting.		
Ore, lean and siliceous, with a few local shale partings.	9 0	Not minable under present conditions.
Ore, oolitic and fossiliferous, in thin bands alternating with streaks of calcite and shale.	2 1	
Ore, shaly	1 3	
Ore	4	
Shale	8	
Irondale (?) seam:		
Ore, siliceous	6	Not minable.
Shale	1	
Ore, siliceous	8	
Shale	3	
Ore, very sandy	1 3	
Shale	1	
Sandstone, ferruginous	7	
Shale, sandy.		

Five miles southwest of slope No. 12 is that part of Red Mountain which lies opposite Bessemer. Here the parting between the upper and lower benches of the Big seam reaches a thickness of 3 feet in places. The upper bench maintains its usual quality and its thickness of 10 to 11 feet, 8 to 10 feet of which are taken in mining. Thin streaks and lenses of shale begin to appear near the top and bottom

of this bench. The lower bench of the Big seam has dwindled down to 4 or 5 feet in thickness and is generally composed of alternating thin strata of ore and shale. The Irondale seam evidently has not been recognized here. Three miles farther southwest the seams show the following section:

Character of Big and Irondale (?) seams at mouth of Potter slope No. 1, Tennessee Coal, Iron and Railroad Company, SE. ¼ sec. 21, T. 19 S., R. 4 W.

Strata.	Thickness.	Character.
	Ft. in.	
Shale.		
Big seam:		
Ore, solid, mined	8 0	Soft ore: Metallic iron, 47± per cent; insoluble, 24± per cent; lime, 0.80± per cent. Soft ore mined at present.
Shale	1 6	
Sandstone, shaly, ferruginous	9	Lower bench.
Ore	3	
Shale	1	
Sandstone with shaly partings	1 6	
Shale	3 0	
Horizon of Irondale seam (?):		
Ore, sandy, lean, with shale partings.	1 0	

ORE BEDS ON WEST RED MOUNTAIN.

On West Red Mountain the rocks dip at high angles and appear not to carry valuable seams of iron ore throughout the middle of the district. At the extreme ends of the district, however, the dips are more gentle, and workable seams have been discovered, for instance, at Compton and Dudley. The two following sections of the Rockwood formation, measured by Charles Butts, show the general character of the beds in the northeast half of West Red Mountain. Comparison of these sections with those made on Red Mountain (pp. 136-139) indicates that the formation thickens to the northwest. The measured thicknesses have been corrected for dip, and the figures represent the computed actual thickness of the beds.

Section of Rockwood formation on West Red Mountain, at Cunningham Gap, in SW. ¼ sec. 10, T. 16 S., R. 2 W.

	Ft.	in.
Chert débris (Fort Payne).		
Sandstone, highly ferruginous, exposed in prospect pit	5	0
Unexposed	39	0
Sandstone	7	10
Unexposed	31	6
Sandstone	2	0
Unexposed	15	8
Sandstone, in massive beds	31	6
Unexposed	15	0
Sandstone	4	0
Unexposed	23	9

	Ft.	in.
Sandstone	5	0
Unexposed	7	10
Sandstone	1	0
Unexposed	15	7
Sandstone	2	0
Unexposed	7	9
Sandstone, ferruginous (shown by prospect pit)	2	0
Unexposed	15	8
Sandstone	1	0
Unexposed	7	0
Sandstone, thick bedded	23	8
Unexposed	31	6
Sandstone, thick bedded	27	8
Shale	2	0
Sandstone, thin to very thick beds, with shale partings	102	0
Sandstone, thin bedded	23	8
Unexposed	47	5
Sandstone	4	0
Unexposed	5	0
Limestone, impure and ferruginous (probably top of Chickamauga).		
	507	0

Section of upper part of Rockwood formation in gap of West Red Mountain, near Dale, Ala.

	Ft.	in.
Shale, black (Devonian).		
Sandstone, greenish predominating, grayish and reddish, evenly bedded, with shale partings, most numerous at top	110	0
Shale, yellowish green	5	6
Sandstone, gray, thin bedded	10	6
Iron ore	2	0
Unexposed	6	0
Sandstone, ferruginous, with decomposed ore	6	0
Iron ore, lean, limy, fossiliferous	10	0
Concealed by very red soil and red sandstone débris	210	0
Limestone (Chickamauga).		
	360	0

Workable ore at Compton occurs in but one seam, which shows the following sections:

Sections of ore seam at Compton mine.

1.		2.		3.	
	Inches.		*Inches.*		*Inches.*
Shale.		Shale.		Shale, ferruginous.	
Ore	13	Ore	17	Ore	7
Shale	1–2	Shale	1–3	Shale	1½
Ore	16	Ore	18	Ore	29
Shale.		Shale.			

1. First right entry, near main slope.
2. First left entry, 300 feet from main slope.
3. Outcrop, near top of mountain.

The seam at Compton ranges generally from 30 to 36 inches in thickness, with a thin parting of shale, irregular in position, as shown in the sections. Locally the entire seam is pinched down to a very few inches or entirely cut out by downward bulging of the overlying shale, which at such places has a concretionary or concentric structure. Such structures, which result in the local disappearance of the ore bed, are erroneously termed "faults" by the miners, but there is no dislocation of the beds and the ore is usually picked up again if the workings are driven on in the same plane.

The extreme southwestern part of Birmingham Valley is partly covered by Tuscaloosa clay and Lafayette loam, but in places buried rock ridges have been revealed by stream erosion. Extensive prospecting by drill, test pits, and slopes has been carried on within the last two years in the region between Dudley and Big Sandy Creek, and the Rockwood formation has been shown to contain workable beds of ore. All the evidence heretofore obtained regarding the somewhat obscure geologic relations of this district indicates that the workable beds of ore are in a strip of Rockwood formation corresponding with McAshan Mountain, 17 miles to the northeast. In other words, the outcrop of the formation here has been repeated by folding and faulting. In the region south of Dudley the beds are completely overturned, so that the dips are to the southeast. This locality is in the Brookwood quadrangle and has been more fully discussed in a previous paper.[a]

MINING DEVELOPMENT.

CHARACTER AND EXTENT.

There have been three stages in the development of the mines in the Birmingham district. The first stage consists of trenching the ore beds along the outcrop on the crest or on the northwest slope of Red Mountain, and of mining the ore from open cuts on the southeast slope. The ore obtained in this way is mostly soft. This method of mining has been possible only where the overlying beds are not more than 20 feet thick and can be stripped off profitably. Most of the mines have passed beyond this stage, but at the Helen-Bess and the Green Spring workings this very profitable type of mining may still be seen.

The second stage of development combines the open cut and incline with underground work. A very fortunate relation between the Big and Irondale seams and the topography of Red Mountain exists in many places, particularly in the northern half of the district, wherever the dip of the Rockwood strata is approximately the same as the southeast slope of the mountain. This slope is cut by narrow

[a] Burchard, E. F., Iron ores in the Brookwood quadrangle, Alabama: Bull. U. S. Geol. Survey No. 260, 1905, pp. 321-334.

V-shaped ravines at intervals of one-half to three-fourths of a mile, and on both sides of many of these hollows the two seams are exposed from the crest to the foot of the ridge. Inclined tramways are built on the flanks of the ravine, and when the outcropping ore has been surface worked entries are driven in on the strike of the ore beds from each side of the ravine and the ore is mined from upsets. A cable tramway may be operated by gravity or by power, depending on the side of the mountain on which the ore is to be delivered. At the Sloss-Sheffield Ruffner mine No. 1 the tracks of the railway which transports the ore to the furnaces are on the southeast side of the mountain, making it possible for cars loaded with ore going down the mountain to pull up the empties, but at the Valley View mine of the Birmingham Ore and Mining Company the ore is hauled up over the mountain and loaded into railroad cars on the opposite side. At mines of this type soft, semihard, and hard ores are obtained, depending on the thickness and character of the cover of the seam.

The third stage of mining, the one to which the majority of the workings in the Birmingham district have now attained, involves systematic underground work entirely. The general plan is very simple, comprising a main or central slope, driven on the dip, from which right and left entries are turned off at regular intervals of 60 to 70 feet. The ore, which is mainly hard, is mined from the upper side of the entry, about 30 feet being left between the entries until robbing is begun. Mules haul the trams to the mouths of the entries, whence the ore is moved up the slope by cable to a tipple, below which it is crushed and loaded directly into cars bound for the furnace. A manway is usually provided at one side of the slope for safety. Comparatively little water is encountered even in the deepest workings of this type, so that a 3 to 4 inch pump usually suffices to drain the mine.

A fourth stage, which some of the workings may reach in the near future, will likely be shaft mining in the basin east of Red Mountain. The working face of the ore bed can be reached more directly by a vertical shaft 300 to 500 feet in depth than by a slope five or six times that length.

Mining conditions at present are doubtless at their most favorable stage. The mining companies are making an effort to utilize all the labor available to increase the output of ore. In the summer of 1906 there were no less than 33 mines actively producing red ore in the district, besides seven or eight workings which have been inactive since the soft ore was exhausted from them. Of the 33 mines in operation 30 are on Red Mountain, within a distance of about 25 miles between Pilot Knob on the northeast and Sparks Gap on the southwest. In places in the middle of the district the underground workings are practically continuous for 3 or 4 miles, and the old surface workings on the outcrop of the ore may be traced without break for 15 miles or more.

The Tennessee Coal, Iron and Railroad Company operates 14 slopes and 1 open cut, collectively known to the iron trade as the Red Mountain group; the Republic Iron and Steel Company operates 5 slopes; the Sloss-Sheffield Steel and Iron Company, 2 slopes and 1 combination working; the Woodward Iron Company, 2 slopes; the Alabama Consolidated Coal and Iron Company, 1 slope; the Birmingham Ore and Mining Company, 1 slope and 3 combination workings. All these companies, except the last named, own their ore mines and blast furnaces. The Birmingham Ore and Mining Company leases its several properties and sells ore to the iron-making concerns.

Besides the mines on Red Mountain, just enumerated, there are on West Red Mountain, at the extreme ends of the district, 2 mines that produce red ore. One is at Compton, operated by the Birmingham Ore and Mining Company, and the other is near Dudley, operated by W. P. Pinckard & Co.

BEARING OF DEVELOPMENT ON ORE SUPPLY.

In July, 1906, the deepest slope in Red Mountain was reported to be 2,100 feet long. This slope is about half a mile north of Reeder Gap. Four other slopes have been driven 1,800 feet each, and there were six slopes between 900 and 1,500 feet long. All the slopes 900 feet or more in length are in the strip of mountain below Birmingham. The newer mines at the extremities of the district have slopes ranging between 200 and 500 feet in length. The 2,100-foot slope goes down on beds whose average dip is 28°, so that its present depth is about 650 feet below the level of the valley at a point directly above the bottom of the slope. Projected at the same angle to a point directly below Little Shades Creek the slope would have a length of about 5,000 feet and a depth below the creek of 1,120 feet. It is not known whether the ore extends with an unchanged dip and thickness to this depth. Drill records obtained farther south in Shades Valley indicate that the ore beds with their associated strata flatten out and locally rise toward the surface. The surface rocks in the valley indicate irregularities in the structure, including faulting, which would naturally be shared by the beds below.

No deterioration in either quality or thickness of the hard ore in the direction of dip has yet been disclosed by the deeper slopes—an encouraging fact in so far as it can be used as a measure of the ore ahead of shorter slopes. At one of the larger mines, centrally located, systematic analyses have been made of the ore at intervals of a few feet from the outcrop to the bottom of the slope and throughout the extent of each entry to the right and left of the slope. The composition of the ore has been found to vary appreciably from place to place and the degree of variation is likely to be as great within a few yards as it is between remote parts of the mine, but the average run of the

mine is remarkably regular. The facts brought out by this series of analyses show that the content of metallic iron increases about 1 per cent for each 1,000 feet away from the outcrop, that the lime (CaO) decreases about 1 per cent in the same distance, and that the silica content slightly increases.

Studies by members of the Alabama Geological Survey extending over many years have shown that the Rockwood formation tends to thin out and become sandier toward the southeast. There is no reason why this change should not be shared proportionately by the inclosed ore beds, and it is believed that the drill records just referred to indicate that such is the case. However, the complete drill records available from the valley east of Red Mountain are so few that reliable conclusions can be based on them regarding the ore basin only in the southern third of the district. Ore can, perhaps, be expected to underlie the valley southeast of Red Mountain, probably as far as Shades Mountain. The width of Shades Valley is a rough indication of the relative extent of the Red Mountain ore toward the southeast, and the width of the valley is sensibly greater southwest than it is northeast of Reeder Gap.

In reference to the theories heretofore advanced regarding the origin of the Clinton ores it may be stated that all the new facts observed in the course of the work in the Birmingham district are in accordance with the hypothesis that the ore is the result of original deposition of ferruginous sediments. The transition, vertically, between sandstone and ore or between shale and ore, is as sharp as that between coal and its inclosing rocks. The variation in composition of an ore bed from place to place is not unlike the local changes in composition and character of a coal bed. The lenslike form of the beds is common to both coal and ore. Finally, as the lens thins, whether of coal or of ore, it tends to become shaly and siliceous. That the ore is due to the replacement of limestone seems hardly possible when it is considered that instead of a decrease in percentage of iron and an increase in that of lime, with depth, until the bed becomes a limestone, almost the reverse has been noted. The lime in the bed is evidently an accessory deposit, as is the silica. The term "depth" in this connection is subject to misconception, for the sediments were deposited in a horizontal position, or nearly so, and their present attitudes are the result of subsequent foldings. The depth to which the beds now extend is therefore incidental, and in no wise affects their character beyond the soft-ore limit. Indeed, the best criterion for judging the character of the unexploited ore beds in the basin southeast of Red Mountain, is the strike section of the same beds that has been afforded by the mine workings. From northwest to southeast there are likely to occur changes similar to those that are known to take place from northeast to southwest. With all these possibilities kept

in mind, the facts in hand still permit a fairly close estimate of the ore reserves in the district, and it is expected that such an estimate will be given in the forthcoming detailed report. It will suffice to state here that this estimate will show probably more ore to be available than has heretofore been supposed by persons not familiar with the district.

Outside of the area of present activity considerable prospecting has been done, especially on the outcrop of the ore-bearing beds. In some places the results have apparently been discouraging, partly because the work has not been thoroughly done, and partly because the outcrop of an ore bed does not tell the whole story. Prospecting with a core drill is expensive, but the information sought in the case of bedded iron ores is of sufficient importance to warrant considerable expenditure. Certain localities may be pointed out as apparently deserving further investigation—for instance, Red Mountain opposite McCalla station and the basin beyond, the strip of the same ridge from Pilot Knob northeastward to the Jefferson County line, and West Red Mountain northeast of Mount Pinson station.

PRODUCTION AND CONSUMPTION OF IRON ORE.

Since 1894 Alabama has held third place among the iron-producing States. In 1905 her total production of iron ore amounted to 3,782,831 long tons, composed of 2,974,413 tons of red hematite, 781,561 tons of brown hematite, and 26,857 tons of magnetite.[a]

The Birmingham district produced in 1905 2,561,264 tons of red hematite, or 86.7 per cent of the total tonnage. The series of mines known as the Red Mountain group are classed among the prominent iron-ore mines of the United States. Together, this group, including the Potter slopes, formerly leased by the same corporation, produced in 1905 1,282,189 long tons, or a little over 50 per cent of the total for the district.

Practically all the ore produced in the district is smelted in the vicinity of Birmingham. The ore is handled by 29 coke furnaces, distributed as follows: In Birmingham city are eight furnaces, four of which belong to the Sloss-Sheffield Steel and Iron Company, two to the Tennessee Coal, Iron and Railroad Company, one to the Atlanta, Birmingham and Atlantic Railroad, and one to the Williamson Iron Company; at Ensley there are six stacks and at Bessemer five stacks of the Tennessee Coal, Iron and Railroad Company; at Thomas, three stacks of the Republic Iron and Steel Company; at Woodward, three stacks of the Woodward Iron Company, and at Oxmoor, two stacks of the Tennessee Coal, Iron and Railroad Company. On the outskirts of the district are the furnace of the Southern Steel Com-

[a] Birkinbine, John, Production of iron ores in 1905: Mineral Resources U. S. for 1905, U. S. Geol. Survey, 1906, p. 56.

pany at Trussville and that of the Central Iron and Coal Company at Holt, near Tuscaloosa.

In general, the furnaces run on a burden of coke, red ore, brown ore, and dolomite or limestone, though certain of them at times use only a self-fluxing red ore. The ores of the district contain too much phosphorus (see analysis, p. 135) to be converted into steel by the Bessemer process, but such pig irons are being very successfully used for basic open-hearth steel making. The open-hearth process is employed by the Tennessee Coal, Iron and Railroad Company at the Ensley rail mill, which consists of ten 50-ton basic Wellman tilting furnaces and one stationary furnace. The entire output of the company's six coke furnaces is transferred as hot metal to the steel mill, where it is made into billets and rails. The use of the open-hearth process as applied to southern ores has passed beyond the experimental stage. The capacity of the Ensley mill is about to be doubled and other steel mills will doubtless soon be built in the district, so that a local market is rapidly arising for southern pig.

THE BROWN IRON ORES OF THE RUSSELLVILLE DISTRICT, ALABAMA.

By Ernest F. Burchard.

LOCATION AND SURFACE FEATURES OF THE DISTRICT.

Russellville, Franklin County, Ala., is in the northwestern part of the State, 25 miles east of the Mississippi State line and 18 miles south of Tennessee River at Sheffield. The Russellville ore district comprises an area of about 25 square miles within a rectangle having dimensions of 8 miles from west to east and about 3 miles from north to south, Russellville being near the middle of its northern edge. The line of the Northern Alabama Railroad from Sheffield to Parrish passes north and south through the area, connecting the ore mines and limestone quarries near Russellville with the blast furnaces at Sheffield. The district lies within the drainage basin of Tennessee River. The northern part of Franklin County immediately surrounding Russellville is a region of comparatively low relief. Russellville has an altitude of about 315 feet above Tennessee River and stands relatively high on the south slope of Little Mountain, the divide between the creeks that flow directly north into Tennessee River and those that make a detour to the west before reaching the main stream. East of Russellville, Payne and Mud creeks, small branches at the headwaters of Cedar Creek, have cut their courses down 100 feet or more below the upland levels, fragments of which remain in the form of flat-topped hills and ridges that show a somewhat even sky line. South of Russellville, toward Sand Mountain, the relief becomes much greater.

GENERAL GEOLOGY.

The rocks exposed from Tennessee River southward to and including the Russellville district are grouped as follows under the formation names employed by the Alabama Geological Survey.[a]

[a] McCalley, Henry, Report on the valley regions of Alabama, pt. 1, Alabama Geol. Survey, 1896 pp. 147 187.

Geologic formations of northwestern Alabama.

System.	Formation.	Character.	Thickness.
			Feet.
Tertiary	Lafayette	Loam and gravel	100+
Cretaceous (?)	Tuscaloosa (?)	Clay	Very thin.
Carboniferous (Mississippian) series.	Bangor	Limestone	200+
	Hartselle	Sandstone	350-400
	Tuscumbia	Limestone	125–175
	Lauderdale	Chert	200+

The rocks lie practically flat in some places and in others have been thrown into broad, gentle folds or domes, with dips as great as 10°. Where any systematic structure has been recognized the folds appear to trend northwest-southeast and to have the steeper dips on the northeast limb, the prevailing dips being consequently to the southwest. The oldest rocks outcrop, therefore, at the north, and toward the south each formation passes in turn below the next younger in the series.

The Lauderdale chert shows only along Tennessee River, while the Tuscumbia limestone floors the wide flood plain of the stream. The area of Hartselle sandstone lies along Little Mountain or the divide between the main Tennessee Valley and the Cedar Creek drainage, and on the summit of the divide it is covered by Lafayette loam. South of this divide, in the ore district, the Bangor limestone, overlain by Lafayette, is exposed by the stream at the headwaters of Cedar Creek wherever they have eroded through the Lafayette materials. Only the lower portion of the Bangor limestone is exposed about Russellville, and here it is thin bedded, shaly, rather argillaceous, and at many places contains characteristic Bangor fossils. The full thickness of the formation is not represented near Russellville. The limestone appears to have undergone erosion to such an extent that a very uneven surface existed at the time the Lafayette sediments were spread over it. The Tuscaloosa formation has not been positively recognized in the ore district, but certain mottled clays that occur along the Southern Railway near the Mississippi State line have been referred to the Cretaceous. The Lafayette materials cover the greater part of the area here considered. Where they overlie the Bangor limestone it is to these two formations that the greatest interest is attached, for in such situations conditions seem to have been favorable to the accumulation of iron ore. The Lafayette sediments probably once mantled the whole area as far east as the Franklin-Lawrence county line, but erosion has removed the material along creek beds and very steep hillsides, so that now the thickest and most continuous deposits are found only on the highest parts of the surface.

THE ORE.

Character.—The ore occurs in irregular masses, bowlders, pebbles, sand, and as cementing material in beds of conglomerate. Its color is dark brown and many fragments have a black, varnishlike luster on botryoidal surfaces of masses that show fibrous structure within. This ore has generally been termed limonite, but the pure ore more closely resembles göthite in composition, as is shown by the following two analyses. It is probably a mixture of göthite and limonite, if it contains these minerals at all, in the proportion of about 7 to 1.

Analyses of clean brown ores from surface, 1 mile east of Russellville.[a]

	1.	2.
Ferric oxide	84.696	83.514
Siliceous matter	3.159	2.864
Alumina	.220	1.411
Manganese oxide	.087	.188
Lime	.440	.407
Magnesia	.025	.045
Phosphoric acid	.765	.760
Sulphur	.054	.085
Combined water	10.444	11.849
Moisture	1.648	.833
Total	101.539	100.206
Metallic iron	59.287	58.459
Phosphorus	.334	.332
Specific gravity	3.616	3.800

[a] McCalley, Henry, Valley regions of Alabama, pt. 1, Alabama Geol. Survey, 1896, p. 213.

If the ferric oxide and the combined water of the above analyses be averaged and then estimated on the basis of a pure ore, the result gives a content of 88.36 per cent of ferric oxide and 11.53 per cent of water. The theoretical composition of limonite, according to Dana, is ferric oxide 85.6 per cent, water 14.4 per cent; while that of göthite is ferric oxide 89.88 per cent, water 10.12 per cent.

In the ore as mined the silica and the alumina run much higher than in the above samples, owing to the presence of clay and of chert gravel which washing may fail to remove. Analyses representing the commercial ores of the district are given below.

Analyses of brown ores from Russellville, Ala., and Pinkney, Tenn.

Constituent.	1.	2.	3.	4.	5.	6.	7.	8.
Iron (Fe)	51.00	50.10	51.07	47.80	49.30	44.29	46.60	46.80
Silica (SiO_2)	11.12	11.80	10.60					
Alumina (Al_2O_3)	6.23	6.02	5.01					
Insoluble				17.00	16.90	20.58	16.80	18.00
Manganese (Mn)	.64	.61	.37				.45	.30
Phosphorus (P)	.52	.59	.64	.44			.88	.95

1, 2, 3, Monthly averages of all ores from the Sloss-Sheffield mines; 4, 5, averages of 5 and 7 cars, respectively, from mines of Sheffield Coal and Iron Company; 6, ore from Alabama-Virginia Iron Ore Company; 7, 8, averages of 10 and 4 cars, respectively, from Pinkney, Tenn.

Occurrence and geologic relations.—The irregular masses of ore, as well as the loose deposits, are found in pockets of varying richness, separated by more or less barren material, either directly upon the Bangor limestone or within the overlying Lafayette formation. As has been stated, the surface of the Bangor limestone is irregular, and many of the ore deposits seem to have been segregated at places where this surface is most uneven. Hollows or depressions in the limestone appear to have been favorable places either for the precipitation of the ore or for the collection of ore débris that has been transported to the region by wave or stream action.

According to position the ore may be divided into two types: (A) masses that lie directly on the Bangor limestone or on the clay residual from the limestone, and (B) loose ore that occurs higher up, mixed with the Lafayette loam. The ore of type A is the more limited in extent, but usually the richer of the two, as it contains gravel only in a few cavities or cracks within the mass. In places over this ore and at the base of the loose loam and gravel of the Lafayette there is a very hard, pebbly conglomerate with siliceous iron-oxide cement. The ore is medium to dark brown in color, and may be granular and easily broken or may be hard and composed of large lumps cemented or welded together. Masses of ore commonly cover or surround a "clay horse" or "white horse," which is a thin reef or pinnacle of light-colored residual clay that grades into the argillaceous limestone below. The clay at a few places contains small amounts of fine-grained ore that may have been compressed into it, but care is taken not to mine more of it than is necessary, for when wet the clay is extremely sticky and can not easily be separated from the ore in the washer. At many places in the hollows of the limestone between the "white horses" the ore is found in solid masses locally 10 to 15 feet thick and containing but little foreign matter. Many bowlders and masses of the ore contain cavities that are partly or completely filled with a fine-grained white to yellow clay or powder, the condition of this filling depending on the quantity of moisture present.

Most of the ore of type B consists of pebbles and lumps, but it also occurs in fragments of all sizes, ranging from a coarse sand to bowlders a foot thick. The Lafayette loam in which this ore occurs commonly contains pebbles of fossiliferous chert and of pink quartz, and these in places enter into the recently cemented conglomerate that lies over the ore of class A. In certain places the pebbles of ore have been sorted and concentrated by nature so as to form huge placer deposits.

The relations of the two types of ore suggest that the ore A was accumulated in pre-Lafayette time, and that the ore B was derived from it mechanically in fragmentary form and worked up into the basal conglomerate and loose gravel of the Lafayette formation.

ORE RESERVES.

Although a considerable area of proved iron-ore lands still await development in the Russellville district, landowners and persons concerned in the iron trade display an ever-increasing interest in the possible distribution of brown ores in other parts of the region. As a general guide it may be stated that similar geologic conditions exist throughout the northern portion of Franklin County and the southern and western parts of Colbert County, Ala., and in the eastern part of Tishomingo County, Miss.; also in parts of the Tennessee River Valley in Tennessee and Kentucky. Therefore many deposits of brown ore that are similar in character to those at Russellville may be revealed by prospecting in these localities. In Lawrence, Lewis, and Wayne counties, Tenn., such deposits have been discovered, and ore is being produced from them at Iron City, West Point, Ferro, Pinkney, Riverside, Allen's Creek, and other points. Although surface indications in the Russellville district have usually led to the opening of good ore below, the surface indications above some brown ore deposits, especially those in the Woodstock, Ala., area, rarely afford a true index of the extent or value of the ores below. In northwestern Alabama and in the Tennessee Valley in general there are no doubt local segregations of ore many acres in extent that do not at all appear at the surface. Small test wells 3 to 4 feet in diameter and 20 to 50 feet deep may be easily sunk in the loose loam and gravel without involving the expense entailed by drilling, and such tests yield the information desired. The main points to be borne in mind are that localities worth prospecting for these brown ores must be underlain by limestone beds which are surfaced with 20 to 100 feet of loam and gravel.

INDUSTRIAL DEVELOPMENTS.

Methods of mining and concentrating.—All the workings of the district are open cuts. The scattered deposits of gravelly ores of type B are worked profitably only on a large scale, involving the use of steam shovels to mine the ore and locomotives to haul it to the washers. Some of the richer deposits will pay if worked out by hand and with mule haulage, provided the washer can be built near by. The ore is all concentrated by means of log washers. The ratio in cubic yards of dirt to tons of ore washed varies from about 3 to 1 in the richer deposits to 12 to 1 in the poorer deposits. The washers automatically remove most of the clay from the ore and all the gravel that will pass a 12-mesh screen; but the results are not thoroughly satisfactory, because the washers fail to separate the ore from the coarser gravel and permit the loss of great quantities of ore that is finer than 12-mesh. The larger pebbles of gravel are removed by hand as the ore passes along a belt toward the storage bin. Water for washing is obtained

from ponds or reservoirs that are supplied by the small creeks of the district. After being pumped to the washers the residue runs into settling ponds, which eventually yield part of the water for use again. Rough estimates indicate that from 2,000 to 2,500 gallons of water are used for each ton of ore washed, but as a general rule much more ore—perhaps twice as much—might be washed with the same quantity of water, since during the operation ore is delivered irregularly, and often no ore whatever is on the screen, while the water must of necessity be pumped constantly.

Operators.—Three companies—the Sloss-Sheffield Steel and Iron Company, the Sheffield Coal and Iron Company, and the Alabama-Virginia Iron Ore Company—are at present mining in the Russellville district. The first two companies mine ore for smelting in their own furnaces; the latter company mines ore for sale only.

The workings of the Sloss Company are southeast of Russellville and cover the greater part of secs. 27, 28, 29, 31, 32, 33, and 34, T. 6 S., R. 11 W. Four washers handle the output of ore, which ranges from 700 to 900 tons a day, all taken by the company's furnaces at Sheffield. The ore is all mined from open cuts. At the first workings east of the town the ore is mined by steam shovel and hauled by a "dinkey" to washer No. 1. The ore from these cuts is entirely of type B. It lies along an old ridge of limestone, the strata of which have been exposed in places by stripping the ore-bearing loam. This loam varies in depth from a few inches to 30 feet, and 10 to 11 cubic yards of it yield 1 ton of washed ore. The ore worked near washer No. 4 is of type A. It is massive and occurs in association with white to greenish residual clays, which overlie the Bangor limestone. Pots of ore 12 to 15 feet deep and "horses" of limestone and clay are mingled together, but above the general level of the highest clay "horses" a rich deposit of ore extends 10 to 20 feet higher, and this is overlain by an equal thickness of pebbly conglomerate and barren loam. The material worked here yields 1 ton of ore for each 3½ cubic yards of dirt, and the entire output of the property washed 6 to 1 in the summer of 1906.

The mines of the Sheffield Coal and Iron Company lie southwest of Russellville, mainly in sec. 36, T. 6 S., R. 12 W., and sec. 1, T. 7 S., R. 12 W. In August, 1906, one washer was in operation, cleaning up about 250 tons of ore daily, which was supplied from a large open cut two-thirds of a mile to the southeast. Two steam shovels load the dirt into cars singly and in trains. The ore is rather fine grained, especially in the upper beds, which are of loam, and it appears to belong to type B, although richer than most deposits of that kind. The deposit ranges from 12 to 25 feet in thickness and is underlain by flat-lying limestone ledges, which are usually covered by a few inches of residual clay. In the SW. ¼ SW. ¼ sec. 35, T. 6 S., R. 12 W., are the

old Parrish mines, now being reopened by the Sheffield Coal and Iron Company. The ore here is strictly of a placer type, but the underlying limestone and residual clay have been exposed in the old workings. This company smelts its own ore at Sheffield.

The third system of mines active in 1906 is operated by the Alabama-Virginia Iron Ore Company in the SW. ¼ sec. 3 and the NW. ¼ sec. 10, T. 7 S., R. 12 W. The ore at this point is gravelly and belongs to type B. It occurs in high banks having at their bases irregular masses of weathered limestone and residual clay. Clay lenses and pockets are mixed with the ore. The ore is loose enough to be broken down with a pick, and at some places a face of ore may be worked down by gravity directly into tram cars. One washer is employed here, cleaning up 400 to 500 tons of ore a week, most of which is shipped to the two furnaces at Chattanooga. It is understood that this ore the only product of the district that is sold on the market commanded in the summer of 1906 $1.40 per ton at the mines, the rejecting point being a minimum of 44 per cent metallic iron.

Fluxing material.—The Bangor beds in this district contain an abundance of good limestone suitable for smelting purposes. The Sheffield Coal and Iron Company operates a quarry and crusher near the ore washer in sec. 36. The stone is taken from that horizon of the Bangor limestone which commonly underlies the ore deposits and comprises oolitic and fossiliferous strata. The composition of the rock as used in the furnaces at Sheffield is shown in the table below (column I). Limestone for the Sheffield furnaces is also obtained from the extensive Fossick quarries in the W. ½ sec. 10, T. 7 S., R. 12 W., 2¼ miles west of Darlington. Here the rock is a uniformly fine-grained, white, oolitic limestone about 27 feet thick. It lies practically flat in thick beds and is underlain and overlain by cherty strata. This limestone is also quarried largely for building and monumental purposes, blocks weighing 25 tons or more having been cut out by means of channeling machines. From 10 to 12 cars a day of fluxing stone and 3 to 4 cars a week of sawed stone are shipped from this place.

An analysis of the Fossick quarry rock, made at the United States Arsenal, Watertown, Mass.,[a] is shown below in column II.

Analyses of Bangor fluxing stone.

Constituent.	I.	II.
Silica (SiO_2)	2	.50
Alumina (Al_2O_3) } Ferric oxide (Fe_2O_3) }	1.40	1.45
Lime (CaO)	54	54.20
Magnesia (MgO)		1.23
Carbon dioxide (CO_2)		42.61

[a] McCalley, Henry. Report on the valley regions of Alabama. Alabama Geol. Survey, 1896, p. 197.

Besides these quarries a new opening and crusher have been estab-hed by the Alabama-Tennessee Stone Company about 1,000 feet st of the railroad station at Darlington. The beds exposed here e nearly flat-lying oolitic limestone, and the product, 250 to 300 ns a day, is shipped to the Sloss-Sheffield Steel and Iron Company's rnaces at Sheffield.

Production of brown ore.—As a producer of brown ore Alabama nks first among the iron-ore producing States. In 1905 there were 1,561 long tons of brown ore mined in Alabama, and of this the ussellville district produced 279,373 long tons, or over 36 per cent. hile some of the Russellville ore is smelted at Chattanooga, prob-ly an equivalent quantity from the Iron City-Pinkney district of nnessee is shipped to Sheffield, so that the production at Russell-lle fairly represents the tonnage of brown ore locally smelted.

Iron making.—It is a matter of historical interest that probably e first furnace erected in Alabama was built in 1818 on the north nk of Cedar Creek in sec. 10, T. 7 S., R. 12 W., a short distance east the present Alabama-Virginia Company's workings. Surface ore as fed to this primitive charcoal furnace and was made into cast and alleable iron. The furnace seems to have been abandoned about 27. Sixty years later, iron making was revived in this region, but a better location in respect to water supply and transporation utes. In 1887, or shortly afterwards, the three stacks of the Shef-ld Coal and Iron Company and the two now controlled by the oss-Sheffield Steel and Iron Company were built at Sheffield, and e furnace, inactive in 1906, also controlled by the latter company, as erected at Florence, across the river. All these furnaces use coke r fuel.

The six furnaces mentioned above produce mainly a foundry pig on that is rather high in phosphorus, but also some mill pig iron. ne practice is to run either entirely on local brown ore and lime-one, or, if the silica is too high—above 18 per cent, for instance—the rden is usually composed of three-fourths local brown ore and one-urth Birmingham hard red ore, with the requisite amount of limestone. nis combination reduces the phosphorus content of the pig iron, and is found that the Russellville ores produce a pig with an appreciably wer content of phosphorus than that introduced by the southern ennessee ores (compare analyses on p. 154). The Tennessee ore, owever, carries a slightly lower and more uniform content of man-nese than the Russellville ore.

As has been noted heretofore, the Sheffield furnaces must freight eir brown ore and limestone 18 to 20 miles and are still less favor-bly situated in relation to red ore and fuel supply, since they obtain eir red ore from Birmingham and the coke consumed comes largely

from the Warrior coal field or from points in Tennessee. These disadvantages are partly offset, however, by the fact that the district is closer to the Mississippi Valley markets than are Birmingham and Chattanooga, and also because there is a market for a portion of the pig iron among local manufacturers. One important enterprise that might be cited in this connection is the Sheffield rolling mill, which consists of 12 double puddling furnaces, 6 heating furnaces, and 4 trains of rolls, and has an annual capacity of 30,000 tons, including such products as bars, rods, and cotton ties.

THE GRAY IRON ORES OF TALLADEGA COUNTY, ALA.

By Philip S. Smith.

TOPOGRAPHY AND GEOLOGY.

The gray iron ores of Alabama occur in a narrow belt that is con-
ned almost entirely to Talladega County. The most northern
:currence of gray ore is in the range known as the Talladega Hills.
, extends in a general northeast-southwest direction, which changes
) a more nearly north-south course in Alpine Mountain. South of
lpine Mountain there is a break of several miles in which faults occur,
) that the iron-bearing members are too deeply buried for profitable
ining under present conditions. About 4 miles south of the south-
'n end of Alpine Mountain the iron members again appear at the sur-
ce in the eastern ridge of the Weewoka Hills, the highest point of
hich is called Heacock Mountain. The general direction of this range
northeast-southwest.

South of the Weewoka Hills the range is formed by Andeluvia
ountain, an unsymmetrical isolated peak with two spurs, one point-
g to the northeast and one to the northwest. Along the southwest
ce of this mountain the range is abruptly terminated by a fault, so
at its connection with the southern continuation of the ridge is
mewhat obscured.

South of this gap the iron-bearing ridge continues for 2 or 3 miles
ith a nearly north-south strike. This portion is cut across by
mauhee and Tallaseehatchee creeks. South of Tallaseehatchee
reek the course of the range abruptly changes from north-south to
. 20° S. and continues thus for about 4 miles to Oden Gap. At
is point the range is cut through by a small northward-flowing creek
nown as Shirtee Creek. From Oden Gap to Fulton Gap the range
tends for about 2 miles in a nearly east-west direction. It then
ntinues with a more northwest-southeast direction for 4 miles and
rms a high ridge known as the Kahatchee Hills.

As far as Fulton Gap the range is rather narrow, at few places over
mile in width, but is well defined and has a single crest. Beyond,

in the region of the Kahatchee Hills, although the highest portion still persists as a single ridge, there are a number of smaller subsidiary ridges, showing great variations in direction, which are formed of the same strata as the main ridge. At the north end of the Kahatchee Hills, beyond the highest point, locally called Flagpole Mountain or Crumplers Peak, there is a cross ridge, with a nearly northeast-southwest trend, which is separated from the main ridge by a fault. This cross range extends within a mile of Childersburg. The western extension of the broken country of the Kahatchee Hills is rather abruptly terminated by a valley occupied by Kahatchee Creek and a creek flowing southward, from near Achates, joining Cedar Creek near Fayetteville. Through this valley, which is a half mile to a mile wide runs the road from Fayetteville to Childersburg.

Two miles east of the junction of Haye Spring Branch and the Coosa, or about 4 miles N. 60° W. of Fayetteville, another range, known as the Katala Hills, extends for 2 miles in a northerly direction. This range then turns abruptly to the east and then to the south and extends southward along the west side of the valley through which the Fayetteville-Childersburg road runs. About a mile west of Fayetteville this range is cut across by Cedar Creek. The Katala Hills are rather low, with few elevations more than 500 feet above the master stream of the region.

South of the gap in the range, through which Cedar Creek passes, the ridge becomes more disconnected, and although it may still be traced by small knobs, it is at some places only a hundred feet above the surrounding country. These low sags across the range are traversed by railroads and roads. Thus the line from Sylacauga to Talladega Springs and Shelby crosses the ridge at a point about three-fourths of a mile southwest of Fayetteville.

South of the railroad pass the range increases in height and in continuity. The northern part of this southern extension, called Chalybeate Mountain, rises about 500 feet above the surrounding country. South of Chalybeate Mountain, prolonging the general southerly trend, is Sulphur Spring Mountain, which is cut through by Peckerwood Creek at Looney Mill. South of Looney Mill the range extends in a more southwesterly direction, decreases considerably in height, and becomes more broken. About 3 miles south of the mill the range is terminated by a great east-west thrust fault.

Near Columbiana, in Shelby County, west of Talladega County, there is another field in which iron occurs in the same relation to the surrounding rocks as in the range already described. The iron, however, is not of exactly the same character as that in the rest of the field, being more like the red ores of Alabama. The range at this place consists of two ridges, which coalesce toward the north and

south forming an elongated ringlike mountain known as Columbiana Mountain. Beeswax Creek cuts entirely across this mountain in its northwest and southeast limbs. The longer axis of the ellipse is northeast-southwest.

Throughout its entire extent the range is tree-covered, and on its gentle lower slopes small, rather poor farms are located. In its upper portions, however, the slopes are steep and are covered with heavy float of coarse conglomeratic sandstone. The summit of the ridge is almost everywhere formed of coarse sandstone that breaks into angular fragments, many of them of large size. The lowland on either side of the range has been eroded on soft rocks, generally limestones or limy shales. The limestones have at many places a very different trend from the ridge-making rocks, so that the contact between these two is generally a fault.

The fact that the ridges stand up above the surrounding country is due chiefly to the protection that has been afforded the weaker underlying rocks by the strong, massive quartzitic sandstones that form the crests of the ridges. In the geological past it is presumable that this whole region was a mountain-built area. By long-continued erosion, however, a nearly continuous plain, practically at sea level, was formed on the hard and soft rocks of which the mountains were made. Later this plain was uplifted and the rivers again began their work of erosion because of the increased slope and velocity given them by the uplift. In this renewed activity it is evident that areas of weak rocks, such as limestones and shales, would be cut down and opened out into larger valleys than areas of harder rocks, such as the sandstones. The ridges therefore do not owe their height to "outbursts" and "upheavals," by which they were elevated higher than the rest of the country, but rather to more orderly, systematic processes of erosion, such as are even now going on, and constantly tending to wear away the softer rocks faster than the harder ones.

In general the structure of the ridge appears to be practically the same throughout the entire region. The typical structure may be well exemplified by a section near Oden Gap. Starting with the dolomitic limestone of the broad valley through which the Central of Georgia Railroad runs, the rocks have a slight southerly dip. As one approaches the ridge the dolomite abruptly gives place to greenish chloritic slates and schists, which also have a southerly dip, at a much higher angle than the dolomite. Higher up the hill and generally nearly at the top of the ridge, there is a heavy quartzitic conglomeratic sandstone with a southerly dip of greater inclination than the slope of the ridge. South of the summit the slope of the surface is not so steep as that of the north side. Here there is a series of slates, schists, and metamorphic sandstones, with occasional seams of iron ore. This

series seems to consist of essentially the same members as those that are found in the float on the north slope. Still farther south the slopes become gentler.

In some places the schistose series is succeeded by thinly laminated slightly metamorphosed light-colored shales with thinly banded limestones. In other places the shales and thin-banded limestones are missing and instead rather massive dolomitic limestones with occasional cherty beds are found. As the dips are all in the same direction the structure of the ridge would seem to be monoclinal, but this interpretation is not permissible, for the dolomitic limestones on both flanks are of the same age.

Further facts concerning the structure of the ridge are afforded in the deep cuts or sections across the ridge. These are formed where streams cut across or where low sags occur which have previously been worn by streams that are now diverted, by capture, from their former courses. A nearly continuous rock section several hundred feet below the summit, traversing the entire ridge, is afforded by the railroad cut which follows Shirtee Creek through Oden Gap. At the extreme north end of this section there is a dolomitic limestone which shows a nearly horizontal dip with a little anticlinal fold at the south end. The limestone abruptly terminates against a series of metamorphic schists that have a greenish color and wavy cleavage. In the midst of these schists are bands of quartzite—very hard, close-textured beds, varying from 1 to 3 feet in thickness, not at all like the heavy quartzitic conglomeratic sandstone on top of the ridge. The first quartzite found in the section is folded into a syncline, the bowl of which is well exposed. This quartzite is much metamorphosed and shows the development of secondary chlorite along the planes of shearing. South of the quartzite and relatively below it are more schists, similar to those previously described. These schists are folded into an anticline and then succeeded by another bed of quartzite. Above the quartzite lies a series of schists, the same as the others, with interbedded iron ores which generally occur rather near the quartzite horizons. The dip of the schists is variable, but the lithological character is nearly constant.

MINES AND PROSPECTS.

Although the occurrence of gray ore in Talladega County has long been known, having been reported by Tuomey in 1858, not much attention has been paid to this source of iron. At the present time only one company, the Gray Ore Iron Company, is in active operation in the district. The Gray Ore Iron Company owns approximately 3 miles along the strike of the formation, but has begun operations at only two points, namely, at the Emauhee mine on Emauhee Creek, and at the Mesaba or Tallaseehatchee mine, on Tallaseehatchee Creek.

Within the limits of this property the range changes from a general north-south to an east-west trend. As the strata show the same change in strike, the same geological horizons still continue from the most northern to the most western part of the property.

The Mesaba mine is the only active mine in the district. It is located on the range where it is cut through by Tallaseehatchee Creek in sec. 10, T. 21 S., R. 4 E. The mine is connected with the main line of the Louisville and Nashville Railroad by a spur track one-half a mile long, which runs from Mesaba to the mine. The creek affords sufficient water throughout the year for the demands of mining.

At present the ore is won mainly by open-cut work, although the time is not far distant when deeper work will be necessary. The ore is trammed from the pits on the different levels to gravity inclines where cars are lowered to the weighing shed, run to the crusher, crushed to 4 inches, and without handling dumped into the ore cars on the railroad. The ore is not hand picked or otherwise sorted or washed.

As the present work is entirely on the surface the ore is more or less broken up and disintegrated, so that a large part may be handled by horse scrapers and shovels. As greater depth is attained and stope mining is begun the ore will undoubtedly become more compact and difficult to break down. This will necessitate recourse to blasting on an extensive scale and consequent increase of cost of mining.

The ore occurs in a series of slates and quartzites which have an easterly dip and a north-south strike. The dip varies in different parts of the mine owing to deformation of the crust through folding and faulting. Although the dip is everywhere easterly there is strong reason for believing that the rocks have been folded to such an extent that the folds have been overthrown, and that in some places this overfolding has been so intense that the rocks have actually been broken and pushed on top of strata which geologically lie above them. The slates and quartzites are conformable—that is, the beds of one lie parallel to the beds of the other. Where this relation is not true the discordance is due to faulting.

The distinction between ore and slate is generally based on purely economic grounds, for the two are so intimately mixed that it is impossible to take out one without also removing a large amount of the other. This fact is of considerable importance in estimating the values of the properties, for the usual analyses do not take into consideration the amount of slate that must be removed in winning the ore.

The faults in this region are of two distinct types, normal and reverse or thrust faults. The normal faults—that is, those faults that have the downthrown block on the side toward which the fault plane dips—trend generally at a right angle to the range. The reverse faults

extend more nearly parallel with the range and have greater effect upon the topography than the normal faults. Most of the normal faults in this district are of slight displacement, but some of the thrust faults have a throw of a thousand feet or more.

The ore occurs in two forms; the first rather hard, massive, and quartzitic; the second soft, crumbly, and slaty. The soft ore is generally higher in iron and is more easily mined. It undoubtedly has been formed by the replacement of slate by iron. The hard, massive ore breaks into angular blocks bounded by joints. On freshly fractured surfaces the ore is seen in glistening small crystals interspersed with quartz grains. Much of the quartz is of a bluish color but on long exposure becomes white and opaque. The quartz grains are crushed and elongated in the plane of the cleavage. The ore is dark, nearly black, but becomes gray on exposure. This change of color is especially noticeable in the slaty ore.

At the Mesaba mine there are two main veins of ore, which differ but slightly from each other either in character or thickness. The eastern vein varies from 10 to 15 feet in thickness. At two places, however, its thickness has been increased by thrust faulting, which took place before the block faulting occurred. This vein has been uncovered for about 600 feet along the strike. Beyond the point thus exposed the evidence afforded by scattered pits is too incomplete to permit valuable deductions as to the structure which may be encountered in further development.

A vein of ore that has been slightly prospected extends from the mine nearly due south for a quarter of a mile and then swings around toward the southeast. It may be traced for about half a mile, but near the junction of the spur track with the main line of the Louisville and Nashville Railroad it is cut off by the fault along the south and east side of the range which brings the limestone to the surface. This vein has an exposed thickness ranging from 3½ to 5 feet. The ore is of the hard variety, being quartzitic, with numerous flattened and crushed grains of quartz.

The second vein at Tallaseehatchee lies about 75 paces west of the eastern one. Toward the south the western vein diverges slightly, so that the distance between the two veins increases in that direction. In the extreme southern part of the area that has been opened at the mine on this vein about 42 feet of ore is exposed. This unusual thickness is due to the reduplication of beds by thrust faulting. Both the eastern and western veins are cut by normal faults that have east-west strikes, no less than five having been recognized in a distance of only 200 paces.

The entire area that has been opened up at the Mesaba mine is included within a square that measures 200 yards on a side. No depth greater than 20 or 25 feet below the surface has yet been attained, so

that the character and continuity of the ore in depth has not yet been determined. It seems, however, that the ore becomes gradually more and more compact with increase in depth.

On account of the slight amount of prospecting that has been done by the company, little is known about the extent and form of the ore bodies. It has been shown, however, that the ore at one or more horizons continues for at least a mile and a half, or to the limits of the company's holdings, south and west of the mine. The amount of float indicates that in at least two places in this distance a great thickness of ore may be expected. Both of these areas occur in sags between hills, but as there are no exposures of underlying rocks at these places the structure could not be determined. It seems probable, however, if the iron series lies below the Weisner formation, as has been supposed, that the apparent thickness is due to the fact that the surface here bevels across the bowls of synclines. This suggestion needs careful and thorough consideration, as its bearing on the economic problems involved is very important.

The other mine of the Gray Ore Iron Company is about three-fourths of a mile north of the Mesaba mine, on the same range, at a point where it is cut through by Emauhee Creek. Operations at the Emauhee have been suspended while work at Mesaba is being pressed. In consequence the pits are filled with water, so that most of the mine could not be visited.

The method of development at Emauhee differs from that used at Mesaba, for the facilities there for stripping are not so good and an incline some 300 feet in length has therefore been driven and drifts have been turned off every 50 feet. The main mining work has been done on the south side of the creek. When the company resumes work the lowest drift will be driven northward at a depth of about 100 feet under the creek and will connect with the surface workings on the other side by an upraise. This connection will afford good ventilation and will block out considerable ground.

The ore at Emauhee is similar to that at Mesaba, but is more dense and quartzitic. This massive character, coupled with the additional expense of underground mining, makes the cost at Emauhee much higher than in the more easily shaken, less massive beds at the Mesaba mine, which for the present, at least, can be handled in open cuts.

There are two veins at Emauhee. The more eastern vein has been most extensively developed and carries the better ore. This vein consists of two benches of hard quartzitic ore separated by a thin parting of iron-impregnated slaty schist, very similar in character to the slates at Mesaba. The thickness of this slate parting varies considerably. In some places it disappears; in others it is several feet thick. The ore also varies in thickness, but near the mine it averages approximately 5 feet 7 inches. This lead has been traced southward and a

small amount of development work has been done 1,000 feet south of the main line. In this distance the ore is nearly continuous with apparently but slight interruption by faults.

North of the mine, across the creek, the main vein has been opened for several hundred feet and a good deal of ore has been won by open-pit mining. In the northern part of the open-cut work, about 200 paces from the creek, there is a well-pronounced fault, with a nearly east-west strike, by which the ore is thrown to the west a slight distance. About 100 paces still farther north there is another east-west fault, by which the ore is thrown some distance to the east. Beyond this point the ore, which has previously appeared on the west side of the ridge, is found only on the east side of the ridge. Other openings have been made on this northward extension from Emauhee nearly to Sycamore. The last place where the ore was exposed along this nearly continuous line was just west of the group of houses at Sycamore, southwest of the cotton mill.

These pits had been dug for a long time and had caved, so that the entire thickness of the ore was perhaps not visible in all of them. There were, however, few if any places north of the open cut on the north side of Emauhee Creek where a greater thickness than 4 feet of ore was observed. The ore in these pits was much redder than that exposed in either the Mesaba or Emauhee mines. It seems evident, however, that this lead is the same as the main lead at Emauhee, which is also correlated with the eastern vein at Mesaba.

The second vein at the Emauhee has not been worked at all. It lies west of the main vein and is of much poorer quality. This ore is an impure iron-bearing sandstone. The vein is wider than the first, averaging about 7 feet. This measurement is approximate only, and can not be made exact owing to the lack of development and the poorly defined contact between the ore and the country rock. Near Emauhee this vein seldom runs more than 30 to 34 per cent metallic iron.

In addition to the Mesaba and Emauhee mines there are a number of other places where gray ore has been mined on a small scale in the past. At Columbiana a few hundred tons were shipped a long time ago. At Andeluvia Mountain, according to McCalley,[a] about 100 tons of ore were mined and shipped. In the Weewoka Hills, near Heacock and Riser mountains, also, a small amount of ore has been mined and smelted.

Active prospecting is now in progress only in the Weewoka Hills near Heacock and Riser mountains. The Heacock property has been exploited by numerous pits, so that the general character of the ore and its width, length, and value have been more or less completely

[a] Valley regions of Alabama, pt. 2.

determined. The ore occurs in a series of arenaceous schists and slates which have a nearly northeast-southwest strike. The main openings are on the west side of the easternmost range of the Weewoka Hills opposite the house of Doctor Heacock in sec. 9, T. 20, R. 4 E. The ore bodies are intricately folded and the structure is complicated. The valley between the western range of the Weewoka Hills on Mallory Mountain and the eastern range on Heacock Mountain is occupied by down-faulted limestone which is of either Knox or Aldrich age. The range consists of schists, slates, and sandstones, and in the extreme upper portion of quartzite.

In the slates there are several beds of gray ore, no less than five being exposed between the foot and summit of the hill on the west side. It seems evident, however, that all of these do not represent separate strata, but rather the folded limbs of the same bed. At least three of the five belong to the same bed, and it is a question whether the other two belong together or to the folded vein to which the first three belong. Many important points regarding the details of these ore horizons can not yet be determined, owing to the small number of openings.

The old work done at the Heacock consisted in stripping the easternmost vein, the one nearest the top of the ridge, for nearly a hundred yards. This vein averages about 3 feet in width and consists of good clean hematite ore. About 100 paces southwest of its northern end this bed is folded back on itself so abruptly that it has broken and the southern continuation has slipped past. The vein, therefore, occupies nearly 20 paces less space than it would if the lead were continuous. This feature is mentioned in detail because it must constantly be taken into account in developing these ores. Where the beds have been much faulted and folded, the value of the ore increases, so that the associated difficulties of mining are in some measure compensated for by the higher tenor of the ore.

In the northwestern part of the field this vein lies west of the summit of the ridge, but its strike, somewhat less westerly than the strike of the ridge, soon brings it onto the east side of the range. It has been traced more or less continuously for about 500 paces, though many of the old prospect pits are now filled in, so that no ore is exposed in place.

About 50 paces west of this vein there is another vein, which stands nearly vertical and has a nearly parallel strike. This vein, where exposed in the entrance of an old adit, appears as a 3½-foot bed. Twenty-three paces within this adit in an easterly direction is another vein which has a flatter easterly dip and a more northwesterly strike. On the surface the two veins have approached each other to within about 4 paces. Consequently it seems evident that the two veins in the adit are the same, for the strikes are converging as well as the dips.

The ore body there is in the form of a northward-pitching anticlinal fold.

Between the two leads shown in the adit and the eastern vein on the summit of the hill there is another lead of ore. This seems to connect with the easternmost vein exposed in the adit to form a synclinal fold. These three veins, then, are presumably the same bed, which has been folded and eroded so as to give the appearance of three separate beds. The westernmost bed on Heacock Mountain has been exposed in only four small pits. It lies about 25 paces west of the vein shown in the mouth of the adit. The ore is identical in character with that seen in the other veins, and all the beds may represent only one ore horizon reduplicated by folding.

In connection with Heacock Mountain it is interesting to note that the direction of the mountain is not parallel to the rock structure, but is determined mainly by the direction of faults on the sides of the mountain. The strata run more nearly north and south than the range, which trends northeast-southwest, and therefore the veins, which all appear on the western side of the mountain in the northern part of this property, cross the range and in the more southern portion are on the eastern side.

About a mile south of the Heacock Mountain openings, on the east side of Weewoka Creek, only a couple of hundred paces from the dam at Weewokaville, there is another series of exposures of gray ore. These exposures occur on a small ridge that is separated from Heacock Mountain by faults which bring down the dolomitic limestones so that a valley has been etched on them. This lower ridge because of the early ownership of the property is called Riser Mountain. It has a heavy quartzitic sandstone at the summit and a series of somewhat metamorphic beds on the lower slopes. These beds, however, are not so much metamorphosed as the slates and schists at the Heacock.

The ore at Riser Mountain is rather complexly cut by both normal and reverse faults. These have, however, not materially affected the quality of the ore, which is of somewhat lower grade than that at the Heacock Mountain property. The most marked effect of the faulting has been to increase materially the thickness of the outcrop. Consequently for a distance of 500 feet along the vein it is wide enough to afford good opportunity for stripping. The ore at this place shows rather more intimate connection with the quartzitic sandstone than at most other localities. The sandstone is rather coarse and in a number of places shows well-marked cross-bedding on a small scale. The ore here occurs in two leads, but owing to the slight amount of development it is uncertain whether they are connected or not. From the rapid thickening and thinning of the main lead it is possible that the thick places represent the fold where the two seams coalesce. On

e other hand, the fact that the two seams have very different thick-
ss is suggestive that they are really two distinct beds.

Nearly a mile south of Weewokaville, on the east side of Weewoka eek, there is another group of openings which shows rather good ore. ne ore, however, is seldom over 3 feet thick and so would be rather pensive to mine. The structure at this place is complicated. The e has a more nearly north south strike, with even a slight tendency ward the southeast. The dip is extremely variable. In the western rt of the field, where it has been opened up by prospect pits, the p becomes nearly flat. This flattening is due in part to the creep of e surface but mainly to the actual change in dip which the rocks ve undergone. Considering the thinness of the beds, their flat clination, and the lower tenor of iron, this property does not seem promising as the Riser or Heacock Mountain fields. This southern ld is abruptly terminated toward the north by a fault and the rthward continuation of the lead has not yet been successfully cated. Throughout the field there are a number of faults of small splacement, most of which seem to be normal faults.

Gray ore float can be traced southward almost continuously to ndeluvia Mountain, though no exploration pits have been put in to ncover the ore. In Andeluvia Mountain at least three veins of ore e exposed. The most valuable occurs on the northwest side, nere 6 feet of good clean ore has been exposed in a prospect pit. ear the summit of the mountain there is also some gray ore, but it is low grade and is merely a ferruginous sandstone with perhaps 25 r cent of metallic iron.

On the summit of Andeluvia Mountain a prospect pit has been sunk d, according to local tradition, about a hundred tons of ore were ipped from it. The ore, however, was so poor that it had no economic lue and further work was abandoned. There are at least two kinds iron ore exposed on Andeluvia Mountain, namely, the gray ore and variety of specular hematite. The amount of the latter, judging om the float, is rather slight and probably this ore has no economic nportance. The specular ore is found in the schists associated with nses of quartz. At many places some iron carbonate or siderite is sociated with the hematite, but it occurs in insignificant amounts.

From Andeluvia Mountain as far south and west as Hickmans Gap, nich is about one-half mile east of Herds Gap, the occurrence of the e has already been described in the paragraphs on the Emauhee and esaba mines. From this point westward as far as Fulton Gap there s been more or less desultory prospecting, but the ore so far exposed s generally been in narrow beds much intermixed with slate. Very tle systematic exploration has been done in this field, however, and rther development work by means of pits and trenches would prob-ly afford interesting results. At least four different beds have been

encountered in a single section across the range near Herds Gap, but their interrelation has not been determined.

In the Kahatchee Hills—meaning by this the range west of Fulton Gap as far as the Childersburg-Fayetteville road—practically no development work has been done, owing rather to the roughness of the country than to the absence of ore indications. At a number of places gray ore float is abundant and several outcrops of ore of fair quality have been found. On the surface the outcrops are generally much weathered and many of them appear leaner than they actually are found to be below the soil.

In the cross range near the northern end of the Kahatchee Hills there is an interesting occurrence of ore which possibly throws light on the origin of some of the gray ore. About 1½ miles N. 50° W. of the highest peak of the Kahatchee Hills there is a quartzite striking N. 53° E. This quartzite contains a great abundance of small pyrite crystals, and near the surface, where alteration has affected the rock most, the iron pyrite has decomposed and weathered into a brown ore on which a pit was opened. Apparently on the same strike and not more than a hundred yards to the southwest there is a bed of very lean gray ore, consisting mainly of hematite. This occurrence suggests the possibility that the gray ore here was derived by metamorphism from brown ore, which in turn was apparently derived from iron pyrite through decomposition.

In the Katala Hills, west of the Kahatchee Hills, there is an abundance of iron float near the summit of the ridge. The line of outcrop of the ore can be traced continuously from a point west of Fayetteville throughout the entire length of the ridge. Along the eastern limb of these mountains the ore is sandy and therefore not of very good quality. In the broken western limb north of Haye Spring Branch the ore is of much better quality. This ore, however, is redder than the other gray ores of the district. This field has not been exploited, but promises well.

South of Fayetteville there are few exposures of good ore. The most promising place is on the southeast side of the spur that runs eastward from Sulphur Spring Mountain, where, in an old pit which has now caved considerably, a lead of ore 6 feet across has been exposed. This lead is said to have shown up much thicker when the pit was first opened. It can be traced southward by float from Sulphur Spring Mountain to Looney Mill, a distance of 2 miles. This float is for the most part highly arenaceous and the iron content of this ore is undoubtedly lower than that of the ore in the northern part of the Katala Hills.

As has been previously noted, the iron-bearing member decreases in value south of Looney Mill, becoming more and more arenaceous, until it is only a slightly ferruginous quartzitic sandstone. In this

art of the range there have been no openings except a few old pits ug in the hard bluish quartzite that forms the summit of the ridge ear the point where it is crossed by a road 1 mile south of Looney Iill.

In Columbiana Mountain, a few miles east of Columbiana, in Shelby County, there is a bed of reddish hematitic iron ore. As its position ith respect to the Weisner quartzite is the same as that of the gray res of Talladega County, mention of its mode of occurrence may be f interest. The structure of the mountain is very complicated. According to Dr. E. A. Smith, the lowland west of Columbiana is formed f Mississippian sandstones and shales. The lowland at the foot of he mountain on the west flank is composed of Knox shales and mestones. Higher up the mountain a fault causes an abrupt tranition into a series of sandy shales with some quartzitic beds. The ummit of the mountain is formed of heavy quartzitic sandstone, such s characterizes the summits of the range in Talladega County. The orm of the mountain is roughly elliptical, the longer axis pointing ortheast-southwest. The massive quartzitic sandstone forms the im of this mountain, except where it is breached by Beeswax Creek the northwest and southeast. The form of this mountain, with its igh elliptical rim and low basinlike central portion, is very peculiar, ut is in some respects similar to the canoe-shaped folded mountains f the northern Appalachians. A section along the Columbiana-Mardis erry road eastward from the summit of the western limb, 1½ miles rom Columbiana, is as follows:

Section along Columbiana-Mardis ferry road.

	Paces.
uartzite, top of ridge	1
ery red soil, all sandstone float	50
early level, practically no float	100
oad descends more abruptly; sandstone with little quartz veins	175
roken shaly sandstone; dip 38° SE	178
roken shaly sandstone; dip 72° E	183
hree-foot quartzite ledge, with numerous quartz veins; dip 47° E	204
laty sandstone; dip vertical	270
laty sandstone; dip 20° E	279
ather heavy fine-grained sandstone; dip 18° E	304
ight-greenish thinly laminated slates quite arenaceous; dip 22° E	374
ne-foot quartzite; dip 22° E	404
leavy quartzitic sandstone	458
leavy sandstone float	517
hinly laminated shales breaking into small pieces; dip E. (?)	538
wo-foot bed of ore forming slight ridge in road	550
ix-inch bed of ore	557
hree-foot bed red iron ore; dip 27° E	560
reenish shaly slates; dip uncertain	564
Fault; beyond this the dip is 48° E	584
reenish shaly slates; dip 30° E	594

	Pace
Coarse sandstone giving rise to deep iron red soil	61
Beginning of another iron series	62
Eastern wall of iron member. This series is made up of a number of thin beds of hematite ore separated from one another by slate partings. The ore is quite quartzose; dip 45° E	63
Sandy shaly slates; dip conformable with iron series	65
Sandy shales; dip 60° E	66
Heavy fine sandstone rather poorly consolidated; dip 37° E	67
Thinly laminated shaly sandstones	7
Heavier sandstone, fine-grained but rather massive; nonquartzitic	7

In the more eastern limb of Columbiana Mountain the iron serie appears on the western slopes. As the dip of the rocks is easterly, th hematite apparently underlies the heavy quartzitic sandstone tha caps the summit of the mountain. This shows the same comple relation that has been observed in Talladega County, namely, that i places the dip of the ore would seem to carry it below the quartzit sandstone, while in other places it appears to be above.

No gray ore has been found in either Alpine Mountain or the Tall dega Hills, but as the same series that occur in the productive area are found also in these hills they may be considered as possible area In the Talladega Hills there are numerous brown ore deposits at th horizon in which gray ore occurs farther south. It would appea therefore, that the horizon of the gray ore is at some places occupie either by lean ferruginous sandstone or by limonite deposits.

The other possibly productive area noted is the western limb the Weewoka Hills or Mallory Mountain. In this mountain althou the rocks appear to belong to the same geological horizon as the of the eastern range of the Weewoka Hills there is no trace of gr ore. Instead, just at the places where gray ore would be expect there are brown ore deposits, a fact that will be further considered i the discussion of the origin of the ore deposits. So far as the prese investigation has shown, however, it does not seem probable th any gray ore of economic importance will be discovered in Alpi Mountain, the Talladega Hills, or Mallory Mountain.

CHARACTER OF THE ORE.

Practically all the so-called gray ore in Talladega County is rea hematite. An analysis made in the chemical laboratory of l United States Geological Survey (No. 2241) of an average sam of ore from Heacock Mountain, Weewoka Hills, gives 70.04 per c Fe_2O_3 and 0.74 per cent FeO. If all the ferrous iron in this analy is derived solely from magnetite the relative percentages of the t minerals would be 97 per cent hematite and 3 per cent magnet

In places, however, the relative percentage of magnetite so increases that the ore becomes somewhat magnetic.

When exposed to weathering the ore takes on a rather ashy gray color, and the name gray ore therefore not only describes it, but serves to distinguish it from the red or the brown ores of northern Alabama. As the ore is a variable mixture of magnetite and hematite the simple term gray ore is sufficiently distinctive and yet implies no definite limitation of the iron mineral.

Thin sections of the ore contain, in addition to the iron minerals, a great deal of quartz, which is the main source of the silica content. There is some feldspar, mainly soda-lime feldspar, although there is also some microcline. Mica as a secondary product is represented by scattered blades of muscovite. Biotite is practically absent. Some chlorite, secondary after mica, is found, but it is not abundant.

The main constituents of the ore are quartz and iron. The hematite is in scaly and apparently sheared aggregates, while the magnetite is generally in well-formed, sharp crystals, which have apparently been formed later than the hematite. In a very few thin sections iron sulphide has been recognized. The quartz occurs in two distinct forms—as an original mineral, very much strained and shattered, and as a secondary mineral, showing no optical stress. This secondary quartz includes many crystals of magnetite, the relations of these minerals showing the relative age of crystallization of the magnetite and the later quartz. Mica was apparently contemporaneous with the later quartz. The magnetite, the later quartz, and the mica were probably formed at the close of the period of dynamic metamorphism during which the mountains were built.

The accompanying chemical analyses bring out more clearly the character of the ores of this district. Table I comprises analyses that have already been published. Table II comprises unpublished analyses, most of which have been collected from mining or prospecting companies, and are less complete than those in Table I. Table III also consists of analyses hitherto unpublished, but these were made from material collected by the United States Geological Survey. The analyses in Table III should therefore receive greater weight than those in either of the other two tables, for the samples were taken carefully and the personal equation was eliminated as far as possible. Samples procured by interested parties are generally misleading, for they are not usually taken across the entire width of the vein which is to be mined. It is practically impossible to select one fragment of rock which shall represent the true value of a vein; therefore some method of sampling which shall be entirely impartial must be adopted. The samples from which all the analyses shown in Table III were made were taken by cutting a continuous groove the entire width of the vein and preserving all the chips from the

furrow and it is therefore believed that these analyses accurately represent the character of the ore.

TABLE I.—*Analyses of Alabama gray iron ore.*

	Location.	SiO_2.	Fe.	P.	S.	MnO_2.	CaO.	Al_2O_3.	H_2O.	Ti.
1	Magnetite near Childersburg	24.60	53.90	0.022	0.04	....	0.32	....	12.00	....
2	Do	10.30	60.40	.065	.06	....	.22	....	.08	....
3	Siliceous hematite, near Columbiana	30.03	42.51	Tr.	.90	0.14	1.94	5.88	1.26	....
4	Do	29.06	44.61	.30	....	1.60	....	3.66	....	....
5	Do	23.45	49.08	.34	.11	....	1.58	4.00	....	....
6	Do	16.24	49.27	.61	.60	.26	1.25	3.31	7.45	....
7	Do	20.74	53.81	Tr	....	.51	....	1.55	....	....
8	SW. $\frac{1}{4}$ sec. 15, T. 22, R. 2 E	40.103	36.272	.330	.037	1.26	.700	13.373	2.078	....
9	NE. $\frac{1}{4}$ sec. 17, T. 21, R. 4 E	38.10	35.17	.36	Tr.	Tr.	.60	6.06	.40	0.00
10	SE. $\frac{1}{4}$ sec. 34, T. 20. R. 4 E	7.05	61.23	.16	Tr.	Tr.	.20	5.10	.10	.00
11	$\frac{1}{2}$ mile south of Sycamore	7.10	59.47	.16	Tr.	Tr.	.80	4.22	.05	.00
12	Sec. 9, T. 20, R. 4 E., opposite Dr. Heacock's	17.35	51.91	.30	Tr.	.31	.80	4.78	.10	.00
13	Do	12.84	56.01	.11	....	....	.50	....	....	....
14	Do	19.30	49.28	.62	....	....	....	....	....	....
15	Do	11.70	54.47	.195	....	....	....	....	....	....
16	Do	4.40	61.37	.666	....	....	....	....	....	....
17	Do	20.80	47.28	.563	....	....	....	....	....	....
18	SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 16, T. 20, R. 4 E	12.75	60.92	.025	....	....	....	....	....	....
19	Do	11.60	59.03	.091	....	....	....	....	....	....
20	Do	33.40	42.89	.15	....	....	....	....	....	....
21	Columbiana Mountain	31.594	31.746	.20	....	....	....	....	....	....
22	NE. $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 17	21.98	46.83	3.00	....	....	....	....	....	....
23	NE. $\frac{1}{4}$ sec. 34, T. 20, R. 4 E	13.80	58.01	.096	....	....	....	....	....	....
	Average	19.94	50.67	.398	.291	.68	.86	5.19	2.613	.00

Analyses 1-3, 6 by E. A. Smith (Porter, Trans. Am. Inst. Min. Eng., vol. 15); analysis 4 by J. B. Britton (Smith, Rept. Progress Alabama Geol. Survey for 1875); analysis 5 by C. F. Chandler (Smith, Rept. Progress Alabama Geol. Survey for 1875); analysis 7 by F. P. Dewey (Tuomey, Second Bienn. Rept. Alabama Geol. Survey, 1858); analysis 8 by A. F. Brainerd (McCalley, Valley regions of Alabama, pt. I, 1897); analyses 9-12 by W. B. Phillips (McCalley, ibid.); analyses 13-20, 22, 23 by W. Crafts (McCalley, ibid.); analysis 21 by Henry McCalley.

From Table I it will be seen that the range of silica is from 4.40 to 40.10, the average being 19.94 for the 23 analyses. The metallic iron ranges from 61.37 to 31.74, averaging 50.67. The phosphorus varies from a mere trace to 3.00, its average value being 0.398. The analysis giving 3 per cent phosphorus differs so much from all the others that one is inclined to suspect some error. Inasmuch as the proof reading on the volume from which the analysis was taken was not carefully done it is possible that the decimal point may have been misplaced, so that instead of 3.00 the value should be 0.30. The sulphur has been quantitatively determined for only 6 of the 23 analyses, but for those the average content was 0.291. Manganese also was found in several of the samples, although in most of them it was neglected. The lime is very low, the average being 0.86 per cent. Alumina is the next highest component after iron and silica. Unfortunately this oxide has been determined in only 10 of the analyses; the average, however, is about 5.19 per cent. A striking departure is seen in analysis 8, in which the alumina rises to 13.37 per cent. The water ranges between 12.00 and 0.05, averaging 2.61.

If the iron is Fe_2O_3, the sulphur SO_2, and the phosphorus P_2O_5 the total of average values obtained from all these analyses is 103.16. The excess over 100 is probably due to the incompleteness of many of the analyses and the inclusion in some of them of two or

more substances under one head. For instance, in some of the analyses undoubtedly all the insolubles are calculated as SiO_2.

TABLE II.—*Analyses of Alabama gray iron ores.*

	Location.	SiO_2.	Fe.	P.	S.	CaO.	Al_2O_3.	Ti.	Mn.	MgO.	K_2O and Na_2O.	Ign.
1	Mesaba mine	24.10	17.90	0.239	0.46	5.10	3.531	0.72		0.176		
2	Mesaba mine	32.10	39.90	.137			5.53		0.25	.30	1.95	4.15
3	Emauhee mine	42.10	30.60	.418		1.12	5.48		.38	.65	1.57	1.86
4	Emauhee mine	25.60	44.10	.404		2.34	.395		.62	1.14	2.11	2.73
5	Mesaba mine	14.72	52.42	.148				.66				
6	Mesaba mine	18.32	48.90	.364				.88				
7	Mesaba mine	15.42	52.28	.147				.71				
8	Heacock Mountain	15.04	53.55	.219								
9	Heacock Mountain	19.58	50.45	.268								
10	Heacock Mountain	18.94	50.70	.284								
11	Heacock Mountain	15.44	52.74									
12	Heacock Mountain	14.10	53.76									
13	Heacock Mountain	22.20	47.79									
14	Riser Mountain	21.64	45.19									
15	Riser Mountain	20.82	46.66									
16	Riser Mountain	24.40	45.20									
17	Riser Mountain	24.00	44.98									
18	Riser Mountain	25.44	44.52									
19	Heacock Mountain	17.00	50.00	.30								
20	Emauhee mine		42.25									
21	1,000 feet south of Emauhee mine		49.15									
22	Mesaba mine		46.85									
23	200 yards west of Emauhee mine		38.02									
	Average	21.63	45.56	.262	.46	1.32	3.73	.74	.42	.57	1.88	2.91

Analysis 1 by A. S. McCreath; analyses 2–4 by B. Crowell; analyses 5–7 by Hillman (Birmingham Testing Laboratory); analyses 8–10 by P. B. Condit; analyses 11–18 by Seifford (Birmingham Testing Laboratory); analysis 19 by Meissner (Vanderbilt Steel and Iron Co.)

Table II is incomplete, for the main elements that prospecting companies wish to determine are the iron and silica. The first of these elements runs considerably lower than the iron of Table I, being on the average about 45.56 per cent. The silica is higher, having a range between 14.10 and 42.10, the average being 21.63 per cent. The phosphorus is much lower, being 0.262 per cent. If, however, in Table I we omit the excessive phosphorus of analysis 13, the average phosphorus of Table I becomes 0.268, which corresponds very closely with that of Table II. There are not sufficient data to permit a comparison of the sulphur of the two tables.

The average of the analyses of Tables I and II is as follows:

Average of analyses given in Tables I and II.

SiO_2	20.78
Fe_2O_3	68.73
P_2O_5	.75
SO_2	.75
MnO_2	.67
CaO	1.09
Al_2O_3	4.46
TiO_2	.26
H_2O	1.30
MgO	.57
K_2O and Na_2O	.94
	100.30

It is interesting to compare this average with the analyses in Table III, which shows the analyses made for this paper by R. S. Hodges, chemist of the Geological Survey of Alabama.

TABLE III.—*Analyses of gray ore from Tallasechatchee mine, Alabama.*

Location.	SiO_2.	Al_2O_3.	Fe.	Mn.	P.	S.	TiO_2.
1. Middle of east vein	32.71	10.18	35.38	0.24	0.28	0.016	0.53
2. Northwest wall of east vein [a]	47.02	......	20.36	......	......	......	......
3. South end of west vein	49.89	......	25.97	......	......	......	......
4. Northern part of west vein [b]	28.34	......	43.17	......	......	......	......
5. South end of west vein [c]	35.68	......	35.96	......	......	......	......

[a] About 36 feet wide.
[b] Vein at this point 38 feet wide. Hard ore.
[c] Vein at this point 42 feet wide. Many slate partings in the ore.

The most noticeable facts shown by the analyses in Table III are the relatively low iron content and the high silica. The greatest amount of iron occurs in the hard, massive variety of ore (analysis 4). Although Tables I and II represent a much greater number of analyses than Table III, the latter is probably more trustworthy, for the ore was not subjected to any sorting in the sampling. The higher percentage of alumina in the only complete analysis in Table III shows that much more slate was included in the ore than would be inferred from the other analyses. The average iron content of the five samples calculated as Fe_2O_3 is 46.14 per cent as opposed to 68.73 per cent, the average obtained from the analyses of Tables I and II. The silica is also much higher, averaging 38.73 as against 20.78.

Calculating the iron as Fe_2O_3, the sulphur as SO_2, the manganese as MnO_2, and the phosphorus as P_2O_5, the complete analysis of sample 1 of Table III would be—

Complete analysis of sample of gray iron ore from Tallasechatchee mine.

SiO_2	32.71
Al_2O_3	10.18
Fe_2O_3	50.54
P_2O_5	.65
MnO_2	.38
SO_2	.03
TiO_2	.53
	95.02

The difference between this total and 100 per cent is probably mainly H_2O.

ORIGIN OF THE ORE.

The origin of the gray ores of Alabama has been discussed in some of the earlier reports, but misconceptions regarding the precise character of the ore have led to untenable hypotheses. In the earliest

ork of the Alabama survey it was stated that the "magnetite" or
ay ore represented a beach accumulation of black sand, such as
curs at many places along the seashore at the present day. This
pothesis has persisted practically down to the present time. Care-
l microscopic examination, however, fails to show that the grains
d been water rounded. In fact, much of the ore has been carried
to its present position since the sedimentary rocks became thor-
ghly consolidated. This fact is proved by numerous specimens
llected and preserved by the United States Geological Survey,
hich show the ore occurring on joint planes of the quartzite at right
gles to the bedding. Then, again, microscopic study shows that
any of the grains of iron ore have clean, sharp crystalline outlines,
hich could only be the case if the ore had been formed where it is
w found; otherwise the grains would have been rolled and abraded
til little of their crystalline form remained.

Another vital objection to the idea of beach accumulation of mag-
tite is the fact that by far the larger portion of iron is hematite.
cording to the analysis of the average sample already noted,
matite formed 97 per cent and magnetite only 3 per cent of the
tire iron content of the ore. It is therefore evident that the ques-
n of the origin of the ore concerns the origin of hematite rather than
gnetite. Beach accumulations of hematite are practically
known, so that it is necessary to believe either that the hematite
s derived subsequently from magnetite or the beach accumulation
pothesis must be discarded. Although instances of alteration of
gnetite into hematite are known, they are by no means common
der the conditions which must have existed in Talladega County in
e geologic past. Besides, it has been proved that the hematite was
rmed earlier than the magnetite. The idea that these iron ores
re originally magnetites which have since been metamorphosed,
inly through deformation and consequent reformation of the dif-
ent minerals, must therefore be abandoned.

It has also been suggested that the ores were originally deposited in
e form of an impure carbonate ore which was subsequently acted
on by great pressure, heat, and moisture. These processes changed
e ore into a magnetite and decreased its volume to about one-half its
ginal size. This hypothesis also seems untenable. In the first
ace the ore is not magnetite. But even neglecting this point and
bstituting hematite for magnetite—for the theory applies nearly
ually well for either—there seems to be no good way of accounting
r the almost entire lack of lime either in the ore itself or in the adja-
nt rocks. If lime were originally present it must have gone some-
here, and must have enriched some region with exactly the same
nount of lime that was lost by the iron ores. In Alabama there

is no evidence of any such enrichment. Neither is there any evidence of a decided change of volume of the ore bodies such as this hypothesis would entail.

It has also been suggested that these ores may represent very basic intrusions rich in iron. Such a hypothesis, however, is impossible, for the ores show stratification. This stratification is recognized by distinct differences in texture and is not at all to be confused with cleavage. Therefore, as the rocks show stratification it is evident that they can not be igneous.

From a study, in both the field and laboratory, of the conditions under which the ores occur it seems clear that the gray ores, in some stage of their development, have been hydrated iron ores, and that their present form is due to the dehydration of the original limonite by the heat and pressure produced by regional deformation. Where such metamorphism affects a deposit of limonite the first result is to drive off the water, thus forming hematite. If, however, under the conditions of metamorphism the ore body was shut off from a sufficient oxygen supply, so that the iron could not be completely oxidized, or if there were CO or some other deoxidizing agent present, the result, as shown by Van Hise, would be a change of the hematite into magnetite and carbon dioxide. The formula for this change would be $3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$. If, then, there were present at the time of metamorphism enough oxygen to completely oxidize a large part but not all of the iron, the result would be the formation of a deposit of hematite with smaller amounts of magnetite. The abundance of the magnetite therefore varies inversely with the amount of oxygen.

The belief that the gray ores were at one time in the form of limonite is based mainly upon their field occurrence. In many parts of the field brown ore deposits occur at essentially the same geologic horizon as the gray ores, and in a few places this connection is so close that the gray ore can be traced into brown ore. The composition of the ores, with their high phosphorus and silica content, also strongly suggests their common origin.

While the gray ores have probably been through the limonite stage it is not believed that the limonite was necessarily the original form in which the iron ore was deposited. The ore occurrence on the northwest flanks of the Kahatchee Hills, already described, illustrates this point. At this place a bed of quartzite was found which had been opened for brown iron ore. After a few tons of this had been mined and the pit excavated to a depth of about 5 feet the ore gave place to a disseminated pyrite body. Here the limonite was undoubtedly the residual concentration remaining after the decomposition and oxidation of the pyrite. The most interesting point, however, in connection with this occurrence is the fact that on the

strike, not over 100 yards distant, there is a bed of quartzitic gray ore which seems to be a direct prolongation of the bed of pyrite. In this place, at least, it would seem that the gray ore had been derived from pyrite, perhaps having been limonite in an intermediate state. Van Hise, however, in his monograph on metamorphism[a] notes that oftentimes the sulphides may be directly converted into hematite through heat and pressure. It is possible, therefore, that the pyrite may have altered directly into hematite without having passed into the form of limonite. Further evidence along the same line is afforded by the ore itself, which in many places shows areas of limonite that were apparently derived from an iron sulphide.

From the facts just stated it would seem that the iron ores are presumably derived from two sources. The first of these sources is pyrite, which may have been formed through the precipitation of iron solutions by the decomposition of organic matter in the quartzite. The second, and probably by far the most important source, was limonite, which was collected in certain horizons where relatively impervious strata succeeded relatively porous beds and so arrested the free circulation of the descending ore-bearing solutions. These limonite beds were subsequently metamorphosed by the great folding and fault movements that the region suffered during the period of mountain building. Where the metamorphism was moderate and where there was sufficient oxygen the limonite was simply dehydrated into hematite. Where, however, the amount of oxygen was not quite sufficient to oxidize all the iron the limonite changed into hematite with some magnetite, the relative amount of the two minerals depending upon the amount of oxygen present.

Some proof of this hypothesis is afforded by the distribution of the different ores. At Columbiana, where the rocks are but slightly metamorphosed, the ore is a reddish hematite with practically no magnetite. In the range near Mesaba and Emauhee the rocks are more metamorphosed and the magnetite increases perceptibly. In another range in the very highly metamorphosed belt near Chulafinnee, in Cleburne County, an iron ore which seems to occur under nearly the same conditions as the ore in Talladega County is almost entirely magnetite.

ECONOMIC IMPORTANCE OF THE ORES.

In regard to the economic importance of these ores there are four main points which must be considered, namely, cost of mining, value of ore, cost of smelting, and opportunities for marketing product. To determine the cost of mining it is necessary to consider the charges for timber, powder, steel, labor, handling of ore and waste underground and on the surface, and pumping. The cost for

[a] Mon. U. S. Geol. Survey, vol. 47, 1904.

timbering will generally be rather low, for the roof stands well. In the Emauhee mine stulls are used only at distant intervals. Even if poor ground should be encountered the local charges for timber are so low that the cost would be relatively slight. The steel and powder charges become high as soon as the hard quartzitic ores are encountered. In the slaty ore these charges decrease to practically nothing. The cost of labor is low, as is usual throughout the South. This low actual cost is somewhat fictitious, for the labor is inefficient and requires much supervision.

The heaviest charges are those incident to the handling of the ore and slate underground. Owing to the fact that the ore is intimately interlaminated with slate, a large amount of dirt must be mined with it. This is costly to handle and reduces the tenor of the ore. It would probably be desirable to hand pick or wash the ore, but either of these operations would add one more item to the cost of mining. The faulted character of many of the veins necessitates much prospecting and makes the mining less systematic than in more regular deposits. Thus considerable extra dead work is performed and extra tramming and handling charges have to be met. Very few data are available as to the wetness of the mines. It is presumable, however, that the pumping charges would be moderate, for the quartzitic beds seem to be quite impervious.

Concerning the value of the ore mined the three tables of chemical analyses should answer the question effectively. It should be borne in mind, however, that the analyses in Table III are of much greater value than those shown in either of the other two tables. The analyses in Table III, as before noted, were not made from selected samples, but from samples taken across the entire width of the vein, including any slate partings that would necessarily have to be mined and could not readily be hand picked. The character of the ore in other essential particulars is also well shown by these tables. The phosphorus content is too high for Bessemer iron, but as much of the southern iron at the present time is open-hearth iron, this is not much of a drawback. There is also a variable but rather high amount of sulphur, which would make the resulting steel brittle.

There are two ways of economically reducing this ore: (1) Smelting independently and (2) smelting in combination with other ores. In smelting several factors need to be considered, especially flux and fuel. The flux can be easily obtained from the limestones and dolomitic limestones on either flank of the ridge. The relative values of pure limestone and dolomitic limestone as flux are still undetermined. Authorities, however, seem united in believing that if there is a small percentage of alumina in the ore some dolomite is at least no drawback. The flux question is therefore easily settled, for anywhere along the range limestone can be obtained within a distance of at most half a mile from the iron ore.

The fuel supply is not a troublesome question, for coal may be tained from the Birmingham district at a distance of not over 50 les from any point in the field. This coal is of good quality and is tensively used throughout the whole Birmingham district. Its lphur content is about 1 per cent.

With such a siliceous ore the cost for flux and fuel will be high, d it would therefore seem expedient, where possible, to use the e in combination with other ores which need a siliceous mixture. Alabama, at the Clinton horizon, there is a great deal of red iron e which is so rich in lime that it is more than self-fluxing. In the ached zone, above water level, much of the lime has been removed om the red ores. Below water level, however, the lime content comes so high that it is necessary to add siliceous ore to counteract e excess lime. At the present time the brown ores or limonites th high silica afford a good mixture. In the future, however, the pply of brown ore will probably not be sufficient to meet the mand, and in that case other siliceous ores will become more sirable than they are at the present time. The reduction of the e that is more than self-fluxing requires practically the same nount of fuel, etc., as that of the ore that is just self-fluxing. It is erefore desirable that the mixture should be nearly self-fluxing. each ton of more than self-fluxing mixture requires the addition a quarter of a ton of siliceous ore to make it just self-fluxing, it evident that the iron of the siliceous ore can be won for practically e same price as the iron of the limy ore alone. It would therefore em advantageous, where the iron content of the siliceous ores runs out 50 per cent metallic iron, to ship this to some of the furnaces elting limy ores and there to use the proper mixture of the two.

Not very much of the gray ore has yet been used in furnaces, so e reports regarding its behavior in the furnace are not based on ng experience. The earlier reports, however, stated that the gray e produced an iron that was too brittle to bear its own weight. e chemical composition of the ore, however, does not indicate at this should be the case. Reports of later furnace tests seem to much more satisfactory. Thus on a furnace run of 200 to 250 ns of gray ore by the Vanderbilt Iron and Steel Company, the port was that "the ore worked well in the furnace, but contains a tle too much magnesia for a satisfactory charcoal iron."

In regard to marketing the product, the main thing to consider is e proximity to railroads. This is not at all a serious question re, for no point in the entire field is more than 4 miles from a railad, and as this distance is almost entirely through open, slightly lling country, spurs could be run to a mine or smelter at slight pense. Furthermore, three railroads cross Talladega County, so at competition ought to keep the freight rates reasonable.

Regarding the other conditions of marketing the products, the same facts prevail in the gray-ore district as in the other iron regions of Alabama. It therefore may be instructive to compare this district with the well-known and successful Birmingham district, noting wherein the costs in one exceed the costs in the other. The cost of mining gray ore will necessarily be the higher on account of its massive quartzitic character, the interlamination of the ore and slate, and slope rather than open-pit mining. The cost of smelting will be considerably lower in the Birmingham district, owing to the lesser cost of coal haulage. The costs of marketing the product from both fields will be practically the same. It seems evident that, in order to offset the greater cost in mining and smelting, the gray ore must run at least 5 points higher in metallic iron than the Birmingham ores.

MAGNETITE DEPOSITS OF THE CORNWALL TYPE IN BERKS AND LEBANON COUNTIES, PA.

By Arthur C. Spencer.

In the autumn of 1906 the writer began a systematic study of those magnetite ores in eastern Pennsylvania that are associated with intrusive masses of diabase at or near the edges of the belt of Mesozoic rocks which enter the State along Delaware River above Trenton and continue in a general southwesterly direction to the Maryland line. Observations were extended over the eastern portion of this belt in Bucks, Montgomery, Berks, Lebanon, and Lancaster counties, Pa., with the special view of acquiring personal knowledge of the stratigraphy and structure of the Mesozoic sedimentary rocks and their relations to the igneous masses inclosed by them. It was rightly expected that this general study would contribute to a better understanding of the geologic relations of the known ore deposits and that it might reveal data which would show where practical exploration might be undertaken for ore bodies that do not appear at the surface.

To complete the investigation as planned, certain parts of the region already covered must be studied in greater detail, and observations must be carried across western Lancaster, Dauphin, York, and Adams counties, Pa., and thence along the continuation of the Newark belt into Maryland. It is hoped that this work may be done early in the season of 1907.

In this preliminary report no attempt is made to set forth in detail the scientific basis for the conclusions that have been reached concerning the origin of the deposits of magnetite ore, the present object being to present practical suggestions that seem warranted by the investigation in its present state of progress. Though full consideration of the origin of the magnetites may wait until the entire field has been studied, the writer's general conclusions on this point are given, since the manner and conditions of ore formation must form a starting point for all practical suggestions looking to the discovery of deposits as yet unknown.

Magnetite ores of the same general type have been worked on considerable scale in Berks County at Boyertown; at two localitie south of Reading; near Fritztown, about 7 miles southwest of Reac ing, and near Joanna station, 2½ miles northeast of Morgantown; i Lebanon County at the Cornwall ore banks, and in York County a various points, but especially near Dillsburg. Of these deposits, onl one, that at Cornwall, is now worked in a large way, though th several former interests at Boyertown have recently been acquire by the Boyertown Ore Company, and it is expected that these mine at an early date will again soon be in operation. Mining in a sma way is in progress at the Wheatfield group near Fritztown, for th purpose of procuring surface ore. The Island and Raudenbusc mines, near Reading, have been abandoned, the former for nearl twenty years and the latter for a longer time. All the deposit named are situated at the northern edge of the Mesozoic Newark bel and the ore at all places appears to lie in limestones or limy shale that belong to the Paleozoic series rather than in strata of the Mesozoi system itself. The Jones mine, near Joanna station, is situated a the southern edge of the Mesozoic belt and the deposit is in Paleozoi strata capped by Mesozoic beds.

The above statement concerning the stratigraphic position of th deposits is practically in accord with the opinion expressed by Lesle and d'Invilliers in their very clear description of the Cornwall mine. All authorities seem to agree that in York County the ores are con tained in Mesozoic strata, and it may be remarked that in at leas three places in Berks County minor deposits of magnetite have bee noted at the contact of invading masses of diabase with sandstone and shales.

A natural deduction to be drawn from the conclusion that all th known large ore deposits of the Cornwall type are associated wit Paleozoic limestones or limy shales is that exploration for othe deposits of a similar nature is most likely to be rewarded if confine to localities where similar rocks occur. Though this is a practica point taken by itself, it is so indefinite as to be of no great value t the prospector, for Paleozoic limestones are of wide occurrence bot north and south of the Newark belt. Some other criterion is there fore required, and such, it is believed, is found in the fact that intru sive diabase at all places lies close to and at most places in actua contact with ore deposits of the Cornwall type. This fact is brough out by every published description of the magnetite deposits, an the present investigation has served to emphasize both the size o these igneous masses and the importance of their relation to or deposits.

It is the writer's view that the intrusive masses of diabase hav been active agents in segregating the iron contained in the variou

[a] Ann. Rept. Second Geol. Survey Pennsylvania, 1885, pp. 491–570.

deposits; or, in other words, that the masses of ore are products of contact metamorphism. Briefly stated, the theory of their origin, which seems to be indicated by all the facts that have been noted concerning their geological relations, is that the magnetite ore bodies of the Cornwall type have been formed by the more or less complete metasomatic replacement of sedimentary rocks, mainly limestones and limy shales, by iron minerals precipitated from percolating heated solutions set into circulation by invading diabase.

Diabase is associated with each of the known ore bodies, but the counter proposition that each mass of diabase should furnish one or more ore deposits is neither warranted by the observed facts nor required by the theory here proposed. As a matter of observation, it is to be noted that in Lebanon, Lancaster, Berks, and Montgomery counties no industrially important magnetite deposits have been discovered within the Mesozoic area. Such properties as the Esterly mine, situated 4 miles northwest of Birdsboro; the Wren mine, 1 mile southwest of Boyertown; and certain prospects near the northwest fork of Perkiomen Creek, about 5 miles northeast of Boyertown, exhibit relatively small masses of magnetite, more or less mixed with pyrite, segregated at the contact between greatly baked shales and intrusive diabase. At two of these places the dip of the contact is greater than 45°, while at the third place—the locality northwest of Boyertown—the dip of the contact may be as low as 20°, and the deposit here is smaller than the deposits at the other places. Here it is notable that the diabase mass next to which the ore occurs is one of the larger masses of the region and one around which there is more than the usual amount of alteration in the invaded sandstones.

On comparing these unimportant deposits with those in the more or less extensively productive mines where Paleozoic strata are involved, it must be concluded that the sandstones, conglomerates, and shales of the Mesozoic system have been very much less susceptible to replacement by iron-bearing solutions than the calcareous strata, mainly limestones and limy shales, of the older formations. The unequal effects of intrusive masses in causing the metamorphism of siliceous and calcareous rocks invaded by them, and especially the greater frequency of metalliferous segregations of contact origin in limestones than in shales and sandstones, are facts of common observation in many fields. Large ore bodies composed of magnetite, pyrite, and chalcopyrite that were evidently formed by the replacement of limestone at or near igneous contacts are worked at several places in California, British Columbia, and Alaska for the copper which they contain, and throughout this region the presence of limestone seems to be essential for the existence of a valuable ore deposit, contacts of intrusive rocks with other sediments being far less favorable for the occurrence of ore bodies.

Diabase intrusions are characteristic of the Mesozoic Newark system throughout practically its whole extent, from Nova Scotia to Richmond, Va., and occur at but few places outside of this Mesozoic belt. Where they do so occur they are found mainly at no great distance from the edge of the Mesozoic belt, and few of them are masses of considerable size.

At most places within the Mesozoic area the diabase occurs as extensive and relatively thin sills between strata of sandstone and shale. Local cross-cutting may be observed, and in certain places the invading rock, though following a group of strata, cuts back and forth across the beds of the group. It is believed that when masses of essentially like size are compared intrusions of this sort offer conditions that are distinctly less favorable to intense metamorphism than those presented by extensively cross-cutting bodies. A deep-seated source for the molten rock must be admitted, and in order to reach the position it now occupies the diabase must have cut through the rocks that form the basement of the Mesozoic system and across the lower strata of the latter as well. Lateral spreading of the invading magma could have occurred only at relatively shallow depths, where the weight of overlying strata would be not too great to be lifted by the pressure acting upon the molten rock. Masses of molten rock injected between the strata to considerable distances, especially if the strata lie at low angles, become isolated from the main source of intrusion. It is evident, therefore, that the degree of alteration of the inclosing rocks depends wholly on the amount of energy residing in the heated mass at the time of its injection. This would of necessity be a limited source of metamorphism. On the other hand, the more steeply inclined fissures through which the sills are supposed to have been fed would afford direct connection with the original source of energy, so that transfer of heat and the movement of mineralizing waters would here be continued through a much longer period.

Undoubtedly different masses of diabase within the same general field may have differed greatly in respect to efficiency in producing metamorphism, but, other things being equal, the amount of variation in the directness of their paths from the original reservoir must have been a very important factor in determining the relative amount of alteration which different masses could have produced. The foregoing considerations indicate certain practical suggestions to searchers for iron ores in this field:

(1) Ore bodies should be sought only at or near the walls of masses of diabase.

(2) Large masses of diabase are more favorable for ore deposits than smaller masses.

(3) Cross-cutting intrusions and highly inclined sills are more favorable than sills of low inclination.

(4) Limestones and limy shales are far more likely to be replaced by ore than clay shales or sandstones.

(5) Particularly favorable locations for ore are found in masses of limestone that lie between masses of diabase and beds of strata that are in a marked degree less susceptible to the metamorphosing influence of the igneous rocks.

(6) The most promising situations will be found at places where the largest number of the above favorable conditions occur in combination.

Many or all of the more favorable conditions enumerated existed at places where the larger ore deposits of the Cornwall type were formed, and as several of these conditions may be fairly inferred to exist at a few other localities, still other deposits of iron ore may yet be found in the same general field. With a view to pointing out these supposedly favorable situations descriptions of the geologic conditions in several districts along the borders of the Newark belt have been prepared and will be presented in the forthcoming report.

THE HARTVILLE IRON-ORE RANGE, WYOMING.

By Sydney H. Ball.

INTRODUCTION.

In the summer of 1906 the writer spent three months in studying the geology and the iron-ore deposits of the Hartville, Wyo., iron range. The following preliminary description of the results of the work will be followed in the near future by a more extended article, accompanied by adequate maps. Some of the conclusions here stated may be modified by a more detailed study of collections and notes. The writer wishes gratefully to acknowledge his indebtedness to Supt. Louis B. Weed, Engineer George C. Botsford, and Capt. Thomas Tucker, of the Colorado Fuel and Iron Company; to Mr. C. A. Guernsey, of Guernsey, and to Messrs. Lauck & Stein, of Frederick.

The literature concerning the iron of the Hartville range is summarized in the following bibliography:

Ricketts, Louis D., Ann. Rept. Territorial Geologist to the Governor of Wyoming, Jan., 1888, Cheyenne, Wyo., pp. 64–68. Briefly describes the geology and mentions the presence of large bodies of iron ore near Sunrise.

Ricketts, Louis D., Ann. Rept. Territorial Geologist to the Governor of Wyoming, Jan., 1890, Cheyenne, Wyo., pp. 51–61. Briefly describes the geology and reports upon the ore deposits in considerable detail, dividing them into three classes: (1) Lenticular masses between walls in crystalline slates, (2) stratified deposits at the base of the cap rock (Guernsey formation), and (3) residual deposits. He describes in detail the development of the Sunrise mine and the presence of ore in a number of other claims in the near vicinity, and from its trend infers that the ore of the Chicago claim is an extension of the Sunrise deposit. He gives a number of analyses of iron ore, all of which are notably high in iron and low in phosphorus and silica.

Knight, Wilbur C., Bull. 14, Wyoming Experiment Station, University of Wyoming, Laramie, Wyo., Oct., 1893, pp. 176–177.

Snow, E. P., Eng. and Min. Jour., vol. 60, pp. 320–321, 1895. General description. Mentions mining by the Indians. Estimates ore in sight at 10,000,000 tons.

Chance, H. M., The iron mines of Hartville, Wyoming: Trans. Am. Inst. Min. Eng., vol. 30, pp. 987–1003. In this excellent report Mr. Chance describes the original pre-Cambrian lenses of ore, as well as the deposits at the base of the Guernsey, and in addition placer and residual deposits. He gives a number of analyses of the ores. Mr. Chance's work is of great value, since he records the conditions in many shafts now inaccessible. This paper is accompanied by a map showing the location of the principal mines and prospects.

SMITH, W. S. T., and DARTON, N. H., Description of the Hartville quadrangle, folio 91, U. S. Geol. Survey, 1903. Describes the general geology, geological history, and economic geology of the Hartville quadrangle. The iron ore is briefly described.

BEELER, HENRY C., Wyoming mines and minerals in brief, Cheyenne, Wyoming, 1904, p. 6.

BEELER, HENRY C., Report of the State Geologist of Wyoming, Cheyenne, Wyoming, 1904, p. 37.

BROOKS, BRYANT B., The State of Wyoming, 1905, Sheridan, Wyoming, pp. 94–95.

GEOGRAPHY AND HISTORY.

The Hartville iron range, lying north and east of North Platte River, is situated in Laramie County, in east-central Wyoming. It forms a portion of the Hartville uplift, a broad and low domal mountain mass similar in many respects to the Black Hills in South Dakota. The maximum height of the uplift is about 6,000 feet above sea level, and the region is one of comparatively little relief. Near the iron mines erosion has detached many hills from the Carboniferous plateau. These are sharp granite peaks or flat-topped buttes capped by horizontal Carboniferous rocks. The area is dissected by intermittent streams, some with narrow gulches and others with broad, wide valleys. The climate is semiarid, and in consequence timber is confined to the higher peaks. Lower elevations are covered sparsely by bunch grass, cactus, and low desert shrubbery.

The iron range extends from Guernsey to Frederick, a distance of 8 miles. The iron-bearing rocks reach a maximum exposed width of 3 miles. The productive area is, however, considerably smaller and extends from Sunrise northeastward 2 miles and from the same point southeastward 1 mile. The towns of the iron range are Sunrise, Hartville, Ironton, and Guernsey. The principal mine of the range and the local offices of the Colorado Fuel and Iron Company are at Sunrise, a village having a population of 1,500. Hartville, a town of 150 people, is supported by the miners of Sunrise. Ironton is the mining camp of the Chicago mine. Guernsey is an ore-shipping town of 150 people. The Hartville iron range has two railroads; the Colorado and Wyoming Railroad extends from the Colorado and Southern Railroad at Hartville Junction to Sunrise and is the line by which the Sunrise ore is shipped; the Chicago, Burlington and Quincy Railroad has built a branch from its present terminus at Guernsey to the Chicago mine.

The history of the Hartville iron range may be divided into four periods: (1) That during which the Indians mined soft ore for war paint; (2) a period stretching from 1880 to 1887, during which the range was a copper-mining district; (3) an iron-prospecting period extending from 1888 to 1897, and, lastly, the period of productive mining, from 1898 to the present day.

The value of the iron deposits of the Hartville iron range was proved while copper was being mined at Sunrise. With the exhaus-

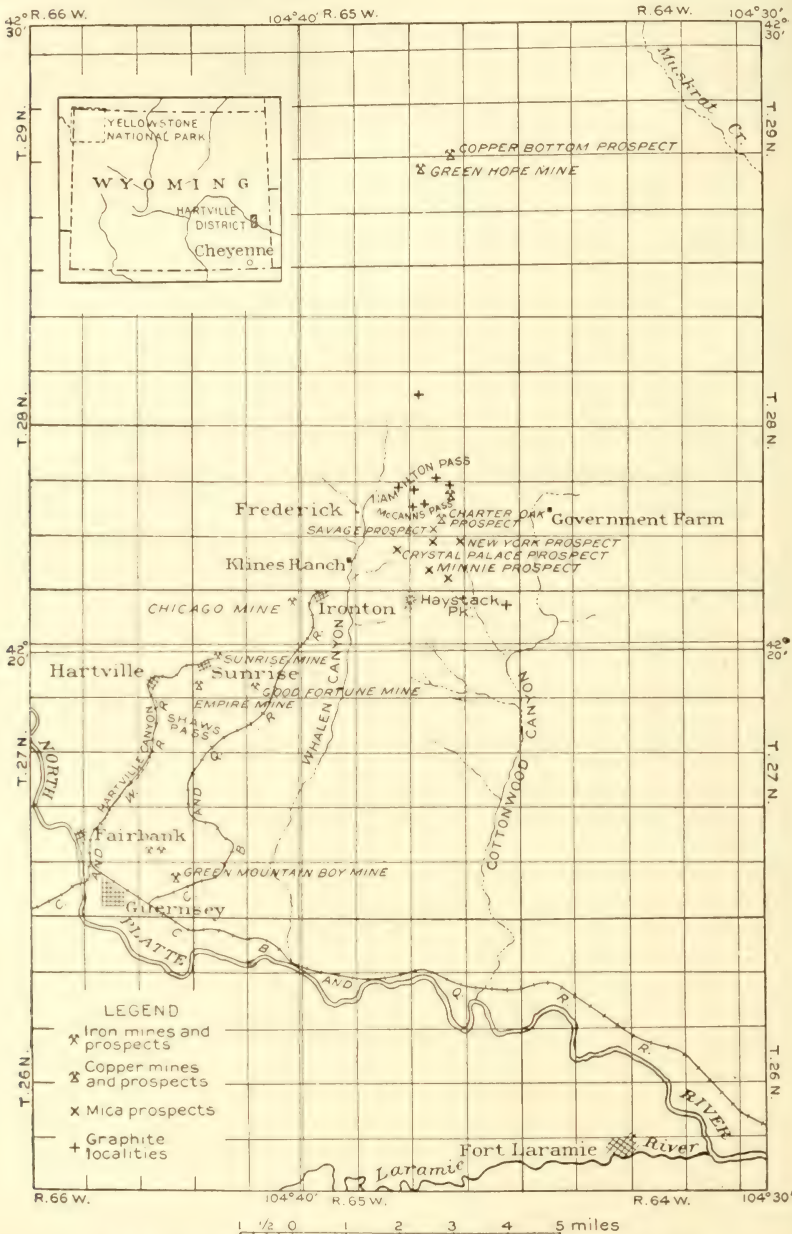

FIG. 5.—Economic map of the Hartville uplift, Laramie County, Wyo.

tion of the copper deposits, Messrs. I. S. Bartlett and C. A. Guernsey began to prospect for iron ore, and in 1900 Mr. Guernsey, having segregated most of the larger deposits, sold his group of claims to the

Colorado Fuel and Iron Company. Since that time this company has been adding to its holdings and now controls most of the more valuable claims. It is rapidly developing two mines, the Sunrise and Chicago, which now furnish the greater portion of the ore used at its smelters at Pueblo, Colo.

PRODUCTION.

The production of the Hartville iron range is tabulated below:

Production of Hartville iron range, 1898–1906.

Year.	Mine.	Quantity.
		Long tons.
1898–99	Good Fortune mine	30,000
1900	Sunrise mine	73,663
1901	do	134,161
1902	do	209,272
1903	do	214,880
1904	do	135,167
1905	Sunrise and Chicago	474,545
1906	do	

In 1905 the Sunrise mine was in point of production the twentieth iron mine in the United States, but two mines outside of the Lake Superior region exceeding it in output. The product of the range shows an encouraging increase, which will presumably become greater from year to year.

GEOLOGY.

STRATIGRAPHY.

The rocks of the Hartville iron range fall naturally into three groups: (1) The steeply dipping pre-Cambrian rocks, (2) the flat-lying or gently dipping Carboniferous and Mesozoic rocks, and (3) the rocks of Tertiary and Recent age encircling the older rocks and filling depressions of erosion extending up into them.

The pre-Cambrian rocks consist of metamorphosed sedimentary rocks and of igneous rocks and their mashed equivalents. The oldest rocks are an interbedded series of siliceous limestones, probably dolomitic, and muscovitic and biotitic schists. In all there appear to be about fifteen beds of limestone and schist, which alternate with one another. The beds vary in thickness from 20 to 500 or more feet. The schist also occurs as lenses in the limestone, these lenses grading both parallel to and across their longest direction into rocks that are intermediate in composition between schist and limestone. The limestone is typically a fine-grained rock of pinkish or grayish color and has a conchoidal fracture. Lenses and beds of cream-colored flint lie parallel to the original planes of stratification and to a minor extent cut these. The schists vary in color from silvery to very dark

gray. They are typically fine grained and pass from biotitic to muscovitic varieties both along and across the bedding. Slaty schists and siliceous schists also occur. Interbedded with this old series are thin beds and lenses of gray quartzose rock and dark-brown or black jaspers.

In the broad schist area east of Sunrise a second sedimentary series lies unconformably upon the uppermost bed of the series just described. The unconformable character of this series is indicated by its location in synclinal troughs upon the uppermost beds of the older rock series, which is folded into a syncline, by a conglomerate that is present in some places at its base, by the fact that it slightly cuts across the beds of the older formation, and by its sharp contacts with and lithological differences from the older formation. This second series of sedimentary rocks is composed of gray, thoroughly crystalline quartzose rocks, which are at some places conglomeratic and at others nonconglomeratic. Associated with these altered sandstones are beds of jasper, which vary in color from gray through browns and reds into black. The banding of the jaspers is at some places close. Although most of the exposures are too poor to determine the younger age of the quartzose rocks and jaspers of all the areas, there is no doubt that two sedimentary series occur in the pre-Cambrian of this district and that many of the areas of siliceous rocks are younger than the schist-limestone series.

The next youngest pre-Cambrian rocks are gabbros, diorites, and allied porphyries and the same rocks mashed into hornblende and chloritic schist. These rocks grade into one another. At most places these igneous rocks are intrusive in the older pre-Cambrian sedimentary series. It is possible, however, that some of the chloritic and hornblende schists may represent later basic lava flows. The age relation of the rocks of the third to those of the second pre-Cambrian series is unknown, since at no place were the two observed in contact, although it is believed from differences in the amounts of folding suffered by the two formations that the sedimentary is the older series. The intrusion of the gabbros and the diorite was followed by that of a coarse-grained pink biotite granite, which at many places contains large feldspar crystals. It occurs in rounded, intrusive masses characterized by but few offshoots and in isolated dikes. Aplites and pegmatites allied in composition to the granite followed its intrusion. The last of the pre-Cambrian series is a diabase which occurs in dikes that are sparsely distributed throughout a wide area.

The Carboniferous series alone of the Paleozoic and Mesozoic rocks occurs in the immediate vicinity of the ore deposits. The Carboniferous consists of a basal member, the Guernsey, and an upper member, the Hartville formation. The Guernsey is normally 150 feet thick and comprises at its base either a conglomeratic quartzite, a

quartzite, or a limestone containing sand grains. The upper part of the formation is composed of massive beds of gray limestone. Prior to the deposition of the Guernsey formation the pre-Carboniferous land surface was reduced to a peneplain. The contact between the pre-Cambrian and Carboniferous rocks is therefore a flat surface that has been locally warped by post-Carboniferous folding. When the Carboniferous rocks are in contact with the pre-Cambrian schist the contact plane is level, while the Carboniferous extends down into the pre-Cambrian limestone in many ramifying rounded bodies. Evidently where the pre-Carboniferous peneplain was underlain by limestone, solution formed caves with attendant cave galleries, sink holes, and irregular solution joint cavities. Unconformably upon the Guernsey lies the Hartville formation, which is at most places 650 feet thick. Its basal member is a deep red sandstone and above this is white or gray limestone. Some distance northwest of the iron range Messrs. Smith and Darton [a] found a number of Jurassic-Triassic and Cretaceous sedimentary formations.

The older rocks prior to late Tertiary times were deeply eroded, and the resulting older gulches, canyons, and valleys have been filled by the Tertiary sandstone, which in the folio already mentioned is called the Arikaree. The Pleistocene formations consist of terrace gravels, alluvium, and wash.

STRUCTURE.

The pre-Cambrian sedimentary rocks have been folded into a complexly folded trough or synclinorium with east and west axis. The axis of the synclinorium passes through Sunrise. The beds of the north arm near Sunrise course north of east. To the northeast they bend farther northward and at Frederick course east of north. North of Frederick the direction of the axis is north-south, its direction being determined by the contiguous granite mass. Between Sunrise and Guernsey the strike of the beds is practically east-west, although in the isolated hills south of Haystack Peak, across Whalen Canyon, the strike is again north-south. Presumably, therefore, beneath Whalen Canyon, east of Guernsey, the beds strike southeastward. In the main schist area east of Sunrise the folding is probably close, since it is known that the schist is repeated by folding at least four times. Minor folds in the synclinorium are of two kinds—(1) those formed contemporaneously with the main folding of the series, and (2) those due to buckling caused by the intrusion of the granite.

Faults, particularly those cutting the extension of the beds of the synclinorium at right angles, are common in the pre-Cambrian complex. The greatest fault in the area, however, extends eastward from a point one-half mile north of Guernsey. Here the pre-Cambrian and

[a] Description of the Hartville quadrangle: Geologic Atlas U. S., folio 91, U. S. Geol. Survey, 1903.

Guernsey formations are in fault contact, the amount of displacement being over 200 feet, with the downthrown side on the south. Brecciation has accompanied both faulting and folding, and the main ore deposits are intimately associated with it. There is evidence also that in some places the schist was opened along its planes of schistosity during the folding.

The Carboniferous formations occur usually as flat-lying remnants capping the pre-Cambrian hill. On the borders of the uplift, however, the Carboniferous formations at many places dip rather steeply beneath younger formations.

ORE BODIES.

FORM AND PLACE OF THE ORES.

The most important iron-ore deposits of the Hartville iron range are lenses that occur in schist on a limestone foot wall. The ore largely replaces the schist, although it partially fills cavities in the schist which are due to jointing, faulting, and brecciation. Detrital ores of secondary derivation from these deposits are situated (1) at the base of the Guernsey formation, (2) at the base of the Hartville formation, and (3) in the Tertiary lake and Pleistocene and Recent stream deposits. The pre-Cambrian jaspers, an amphibolitized phase of the schist, and the matrix of some of the conglomeratic facies of the second pre-Cambrian series, also locally contain considerable iron.

The most important ore deposits next to the lenses above the contact of the pre-Cambrian schist and limestone are situated along the fault already mentioned, north of Guernsey, between the pre-Cambrian series and the Guernsey formation. Although but little developed, these deposits will perhaps repay careful prospecting. Masses of hematite and limonite in the Haystack Mountains are evidently the iron hats or gossans of sulphide deposits and are economically important.

LENSES OF IRON ORE IN SCHIST UPON A LIMESTONE FOOT WALL.

GENERAL CHARACTER.

The principal bodies are irregular lenses, elongated parallel to the strike of the metamorphic sedimentary rocks in which they occur. Their range in width is from a few to 100 feet or more, and some of them are over 1,000 feet long. It is reported that one ore body in the district has been proved to a depth of 900 feet. The principal deposits of this type include those of the Sunrise mine and its practical extension—the Lone Jack—and the Chicago and the Good Fortune mines. Similar ore masses occur at a number of points between these ore bodies.

ORE AND GANGUE MINERALS.

The chief ore of these deposits is hydrated hematite. It is either (1) a hard gray ore filled with numerous cavities, which are lined with finely crystalline specular hematite, or (2) a soft greasy ore of brownish-red color. Fibrous varieties of hematite, including mammillary ore, grape ore, and stalactitic ore, occur less frequently. Minor quantities of siderite and limonite are associated with the hematite. The limonite is in some places compact and finely granular; at others it is mammillary, and at still others it is a soft yellow ocher. Magnetite is not present in masses large enough to attract the eye, although slight local magnetic variations noted at some places in the vicinity of the ore deposits may indicate its presence. Pyrite and marcasite were not observed and probably do not occur in the ore bodies.

The gangue minerals are calcite, quartz, gypsum, chalcedony, barite, and a kaolinlike mineral, and the copper minerals are chrysocolla, malachite, chalcocite, azurite, and native copper. Calcite occurs in colorless or slightly yellow crystals. The most important development of quartz, like that of calcite, is clearly later than the ore. It also occurs as brecciated fragments in the ore and is then older than the hematite, while to a less extent it is contemporaneous with the ore. At the Chicago mine the quartz sometimes is of a beautiful amethystine tint. The copper minerals [a] occur in fractures in the hematite and associated rocks and are the younger.

Irregular masses of iron-stained schist, "soapstone," and to a less extent iron-stained limestone and iron-stained siliceous rocks occur as vein material in the ore bodies. Schist and soapstone occur as irregular horses throughout the ore body. The "soapstone" is an unctuous substance of pale green color.

PARAGENESIS.

The hard and soft ores grade into schist and it is evident that each was formed through the replacement of the schist by hematite. The soft ore is thus in part derived directly from the schist, but a considerable portion of it is derived secondarily from the hard ore. Pseudomorphous replacements of hard ore by soft ore are common. Perhaps the best evidence of this change is seen in the pebbles of soft ore of beautifully rounded form that occur in the detrital deposits at the base of the Guernsey formation. Pebbles of this formation are usually of the dense hard gray ore, and it is absolutely impossible that a substance offering as little resistance to attrition as the soft ore could form such well-rounded pebbles. The secondary character of much of the soft ore is further indicated by the fact that on

[a] See this volume, pp. 93–107.

the surface at the Sunrise mine the soft ore equals the hard ore in bulk, while on the lowest levels hard ore greatly predominates. In the Lone Jack tunnel, which after entering the hill gains considerable depth beneath the surface, the soft ore gradually decreases in amount from the entry of the tunnel to the breast, and at the latter point is practically absent. Alteration of the hard ore into the soft by percolating waters is well exemplified by the presence of soft ore along channels of maximum water circulation. There is also reason to believe that soft ore originates from the hard through shearing, since it occurs along many fault planes in the ore bodies.

The mammillary, grape, and stalactitic forms of hematite are clearly younger than the hard ore and in most places are younger than the soft ore. The mammillary ore occurs in fractures cutting the hard and soft hematite, while the grape and stalactitic ores cover cavities in the older varieties. Some of the mammillary ore was undoubtedly formed after the deposition of the detrital ore at the base of the Guernsey (Carboniferous) formation.

Limonite is a product of the surface alteration of the other iron-ore minerals. It occurs as pseudomorphs after both hematite and siderite. Great rounded bodies of limonite associated with an iron-stained flint are found in the Lone Jack and Sunrise open pits immediately beneath the Carboniferous rocks. The limonite and flint grade, on the one hand, into schist and, on the other, into hematite and are evidently a product of the surface alteration of the schist. Siderite occurs in cavities in the hematite and is clearly younger than it. After the deposition of the siderite came that of quartz in small crystals. Quartz is in turn at places coated with calcite. Of earlier origin than either the quartz or the calcite are the copper ores. These copper ores were, in the main, deposited after the Guernsey formation had been laid down, and in consequence the quartz and calcite were evidently formed in Carboniferous or post-Carboniferous times.

GRADE OF ORE.

The ore of the Hartville iron range is a high-grade hematite, some masses of which contain over 68 per cent of iron, although the ore as a whole will probably not average over 60 per cent. The iron content, where the contact of the ore and country rock is a fault, usually holds its grade up to the fault plane. The iron content in the Sunrise mine increases perceptibly with depth, indicating, perhaps, a considerable redeposition of iron at depths through secondary processes. The ore of the Hartville iron range examined by early writers was very low in phosphorus, many samples showing only a trace. At the present time much of the ore shipped is of a non-Bessemer grade. The earlier analyses are believed by the officers of the Colorado Fuel and Iron Company to have been made from picked

samples, since their analyses from the same points show a higher content of phosphorus. Some of the ore is high in silica, its only other detrimental constituent. Sulphur, so far as known, is absent, while the copper minerals occupy such restricted areas that their presence is not troublesome in the sorting of the ores. The ore is rather heavy, occupying approximately 10 cubic feet per ton.

DISTRIBUTION.

The iron ore lenses all occupy similar positions in relation to the inclosing rocks. They lie in schist immediately above the uppermost limestone of the older pre-Cambrian series. This limestone swings from the Good Fortune mine east to Whalen Canyon, where it is covered by alluvium. Since limestone does not outcrop on the east side of Whalen Canyon south of this point the contact is perhaps situated near the center of the valley. In the other direction the contact courses from the Good Fortune mine north of west to a point where it passes beneath horizontal Carboniferous rocks. The contact between the schist and limestone in this direction is again exposed in the Republic shaft at the tail of the railroad Y in Sunrise. From here it courses to a point beneath the Colorado Supply Store, from which it goes north and then northeast, forming the foot wall of the Sunrise ore body. Thence it bows out to the northward, passing north of the Biwabik shaft beneath the Carboniferous, and appearing at the surface again 100 feet north of the Chicago open pit. The contact here is hidden in a valley, but appears again on the hill west of the Colorado Supply Store at Ironton. After passing beneath the alluvium of Whalen Canyon this contact next appears in a hill south of the house at Kline's ranch. From this point it courses practically due north to Frederick, where it lies slightly east of the ranch house. Along this contact, then, all of the larger iron deposits of the Hartville iron range occur.

The presence of large ore bodies is determined apparently by the minor structural peculiarities of this contact. For instance, in the Sunrise mine the two richest bodies of ore lie in minor synclines superimposed upon the main syncline. At the Good Fortune mine the ore is closely associated with a sharp minor fold accompanied by considerable brecciation. At the Sunrise mine the hanging wall and the foot wall are both schist, although on the foot wall the schist between the ore and the underlying limestone is thin. At the Chicago mine the ore on the north side is directly against the limestone or its iron-stained alteration products. At the Good Fortune mine a thin shell of siliceous iron-stained schist separates the ore from the underlying limestone. The contact between the ore body and the country rock is in some places sharp and in others gradational. On the whole, gradational contacts are probably more common, and it

is evident that the ore is but a replacement of the schist, since no hard-and-fast line can be drawn between unaltered schist, iron-stained schist, siliceous ore, and good ore. Where the contact between the country rock and the ore is sharp, considerable differential movement has taken place, and most of such contacts are lines of recognized faulting.

ORIGIN OF THE ORES.

The ore lenses in the pre-Cambrian rocks are of secondary origin. This is proved by the close relationship between them and secondary structures, such as folding, jointing, faulting, and brecciation. Further, the ore was deposited by descending water. This is indicated by the position of the ore along a contact which is a maximum zone of downward water circulation and by the presence of lenses and veins of iron ore at a distance from the main ore bodies along joints and faults, natural sites of maximum water circulation. Further, the ore is associated with calcite, quartz, and limonite, minerals known to be deposited by water. Circulating waters naturally flow in some pervious stratum above an impervious bed, or follow more or less open channels along zones of maximum rock crushing. That the limestone is relatively impervious and the schist relatively pervious is indicated by a number of the characteristics of these rocks. Thus the pre-Cambrian diabase dikes in limestone are comparatively fresh, while those in schist are greatly altered. Likewise veins of pegmatitic quartz, presumably deposited by very dilute aqueous solutions, are much more abundant in schist than in limestone. Further, the limestone, when folded, appears to have escaped important brecciation, while the more siliceous bands of the schist were intensely fractured. The limestones naturally confined the circulation of the water to the more pervious rock that overlay it. The main circulation, then, was in schist down the dip slope of limestone. The faults crossing the pre-Cambrian formations would furnish outlets by which the descending water could reach the surface. From the depth of the deposits it is inferred that the topography, when the ores were deposited, was of a rugged character.

The possible sources of the iron ore are (1) magnetite, hematite, and pyrite in schist; (2) pyrite in quartzose beds; (3) iron carbonate in the limestone; and (4) hematite in the pegmatite veins.

Pyrite and magnetite are very common minerals in much of the schist of the Hartville iron range. Pyrite in diamond-drill cores of biotitic schist occurs usually along the planes of schistosity in very small flakes. In the muscovite schists, particularly in those near the ore bodies, are many tiny cavities which are heavily iron-stained. Some of these represent hematite and magnetite crystals; others are, without much question, the casts of small crystals of pyrite, which,

to judge from their even distribution throughout large masses of the schist, were original to the recrystallization of the schist. Pyrite also appears to be present as an original constituent in some of the quartzose beds interbedded with the schist member. The chemical composition of the schist shows that it had a low iron content prior to its alteration.

Locally there are probably small amounts of iron carbonate, ferruginous dolomite, or ferruginous calcite in the limestone. The unstained character of much of its weathered surface, however, indicates that the quantities of such minerals in the limestone are so small as to be absolutely inadequate to supply material for the concentration of large iron-ore bodies. Further, this iron carbonate of the limestone lies below the main course of circulating waters. In the schist and limestone there are a few quartz veins, probably of pegmatitic origin, and a small amount of hematite forms a constituent of these veins. The rôle of the pegmatite as an original source of the ore may, however, be neglected.

It is believed, then, that the iron ores were concentrated by surface waters from magnetite and iron pyrite of the schist lying above the limestone foot wall. During pre-Cambrian erosion large bodies of this schist were carried away, and carbonated surface waters probably broke down the iron minerals into iron carbonate or other soluble iron salts. This material was carried downward in solution along the impervious limestone foot wall, where it was precipitated by oxygen-bearing waters descending more directly from the surface through cross faults or other passages of free water circulation

AGE OF DEPOSITS.

These lenses of ore were evidently formed after the pre-Cambrian rocks had been subjected to the synclinal folding, which has already been described. This is shown by the fact that the position of the ore deposits depends closely upon rock structure. As to the relative age of the granite intrusion and the ore deposition certain evidence is lacking, although it is believed that the ore was deposited after the granite was intruded. This much, at least, is certain that in the ore deposits there are zones of brecciated quartz, which were probably once pegmatitic veins cutting schist that is now replaced by ore. It is also certain that in the main the ore was formed prior to the deposition of the Guernsey formation, since this Carboniferous terrane locally contains at its base pebbles of hard ore similar to that of the Sunrise deposit. To provide water circulation adequate for the deposition of bodies of iron ore that lay so deep the topography at the time of their formation must have had sufficient relief to cause deep circulation of surface waters. In consequence it is probable that the ore was

deposited long before the production of the peneplain, which preceded the deposition of the Guernsey formation. After the iron ore was deposited, surface waters modified the deposit, forming considerable bodies of soft ore along planes of maximum circulation, a like effect being produced by movement along shear zones. Further, limonite has been formed along some of the water channels of the past and the present day.

RULES FOR PROSPECTING AND GROUND FAVORABLE FOR PROSPECTING.

The restriction of the important ore bodies of the Hartville iron range to a single contact has already been mentioned and the extension of this contact has been described. In prospecting it the diamond-drill holes should be located in the schist area at a distance of from 400 to 600 feet from the foot wall of limestone. Where the contact is covered by alluvium, as it is from Ironton to Kline's ranch, it will be necessary by churn or diamond drill to more accurately locate this contact. Drill data indicating the presence of minor folds should be carefully sought, for ore will probably be found in minor synclines. Whether this portion of the contact will prove as rich as that which has already been prospected may be questioned, but ore bodies probably exist within this new prospecting ground. The proximity of the detrital Carboniferous ore bodies, later to be described, is a further help in prospecting, since they are apparently confined to the immediate vicinity of iron-ore lenses in the pre-Cambrian rocks. The dial compass and dip needle are valueless for use in this iron-ore range, since considerable bodies of the iron ore are nonmagnetic, while some of the noniron-bearing formations, such as the gabbro, affect the needles appreciably.

The conditions that determine the presence of iron ore along the contact already described appear to be (1) the folding to which the rocks have been subjected and (2) the presence of a thick body of schist—to serve as a source of the ore—superimposed upon an impervious body of limestone. The schist-limestone contacts throughout the range are similar to this one as regards the folding. In most places, however, the schist above the limestone is too thin to be the source of large ore bodies. The only probable exception to this statement is the contact between the schist and limestone in the west half of sec. 26 and the east half of sec. 27, T. 27 N., R. 66 W. Along this contact north of the furnace at Fairbank there is a hill of pre-Cambrian limestone. North of this hill is a wide valley, beyond which pre-Cambrian muscovitic schist is exposed. This schist is very thick, and beneath it the limestone dips northward at an angle of 70°. It is believed that this contact, which is hidden in the valley, is worth careful prospecting. Farther north of east, in sec. 26, hornblendic schists cut out the muscovitic schist. The large

body of detrital ore at the base of the Guernsey formation, 1,850 feet south and 525 feet west of the northeast corner of sec. 26, may have been derived from some pre-Cambrian ore lens along this contact.

DETRITAL ORES AT THE BASE OF THE GUERNSEY FORMATION.

The basal bed of the Guernsey formation, which is at many places iron stained, is a quartzite or a limestone containing clastic grains. When conglomeratic the pebbles ordinarily consist of quartz, but locally of iron ore. The iron-ore pebbles are usually confined to the immedate vicinity of known deposits of pre-Cambrian iron ore. The pebbles are well rounded, many of them being beautifully polished, and reach a maximum diameter of 1 foot. The ore is typically the hard gray ore, which in some places has been altered to soft ore. Where such iron-ore pebbles with the associated iron-stained quartzite lie in the irregular sink holes and cave galleries that extend into the pre-Cambrian limestone (see p. 195), the ore has in many places been considerably recrystallized. Each sink hole, when partially cut away by erosion, has acted as an impervious trough, in which iron has been concentrated by downward circulating waters. In consequence the quartzite is wholly or partially replaced by red hematite, which is often of excellent grade. In places the detrital iron-ore pebbles are intact; in others they have been completely destroyed by recrystallization. Calcite, quartz, chalcedony, siderite, and copper ore are at many places closely associated with this hematite and ordinarily fill fractures in it. So far as known, none of these deposits are of large size, and as a rule the ore is too siliceous to be of economic value.

DEPOSITS AT THE BASE OF THE HARTVILLE.

The base of the Hartville formation is an iron-stained sandstone which at a few places contains small pebbles of iron ore. The material of these pebbles was directly or indirectly derived from pre-Cambrian ore bodies through the breaking up of the detrital pebbles of the Guernsey formation. North and west of Hartville the base of the Hartville formation at a number of places is an iron-stained shale, upon which lies the typical Hartville sandstone. Where this shale has been folded into gentle synclines the iron of the sandstone has been redeposited upon the shale, and in consequence blanket beds of low-grade hematite mark this horizon. Ore bodies of this class will probably never be of economic importance.

RESIDUAL AND PLACER ORE.

In the early days of mining at Sunrise the surface was covered by bowlders of iron ore which were derived from the breaking down

of the pre-Cambrian iron-ore body at that point. Although large amounts of this ore have been shipped, iron-ore float even now occurs throughout the productive portions of the iron range.

Pebbles of iron ore are found in the bed of Platte River some distance below the town of Guernsey. At Guernsey they are 1 inch or less in diameter and increase gradually in size upstream. The pebbles do not occur in the Platte above the mouth of Hartville Canyon, but are found in the canyon as far up as Sunrise.

IRON IN OTHER PRE-CAMBRIAN ROCKS.

The jasper of the second pre-Cambrian series contains at many places some hematite and limonite. Veins of hematite occurring in fractures cut it and irregular masses of hematite cement its brecciated fragments. The jasper itself is also more or less replaced by hematite and limonite, but no considerable body of ore has yet been discovered in it, and most of the ore found in it is probably too siliceous to be of value. South of Shaws Pass a peculiar metamorphosed type of the pre-Cambrian schist, containing a large amount of amphibole, is heavily iron stained. The matrix of the conglomeratic phase of the second pre-Cambrian series contains at many places considerable iron, but none of the prospects in such rocks have yet proved valuable.

DEPOSITS ALONG THE FAULT CONTACT OF THE PRE-CAMBRIAN AND THE GUERNSEY LIMESTONE.

Along a line beginning approximately one-half mile north of Guernsey and extending eastward across low hills to Whalen Canyon, the Guernsey formation and the pre-Cambrian rocks are in fault contact. The downthrown side of this fault is to the south and appears to have been dropped more than 200 feet. The fault plane is everywhere iron stained and a number of prospects are situated along it. Three shafts in the south-central portion of sec. 25, T. 27 N., R. 66 W., owned by Mr. C. A. Guernsey, are within 100 feet of one another. The northern or hanging wall of the ore body is smooth, and the contact between the ore and the pre-Cambrian limestone is sharp. Farther south the ore passes gradually into iron-stained Guernsey limestone. The iron ore lens, consisting of good soft and hard grades, is from 2 to 6 feet wide upon the surface, and widens somewhat toward the west. At the bottom of the shafts, which range in depth from 24 to 60 feet, the lens is somewhat wider and apparently increases in thickness with depth. One-quarter of a mile west of this locality several shafts and tunnels develop other ore bodies in breccia zones within the pre-Cambrian limestone, parallel to this fault. The ore here is a black pulverulent hematite containing considerable calcite and siderite. The appearance of the ore indicates that it contains manganese. Not

enough development work has been done upon the ore bodies of this fault plane to determine satisfactorily either their commercial possibilities or their mode of origin. It is certain that prospect work should be confined to the fault contact between the two formations. These iron-ore lenses were deposited by water which circulated along the fault plane. It is unknown whether the water which formed the iron ore ascended or descended along this plane, although the close resemblance of the ore to much of that of the pre-Cambrian type indicates that the lenses were deposited by descending waters. In this connection, however, the apparent thickening of the ore bodies in depth should be borne in mind.

GOSSAN DEPOSITS.

In the Haystack Mountains, particularly in McCanns Pass, comparatively large areas are covered by a low-grade hematite, with which is associated some limonite. These minerals cement irregular fragments of schist. Here and there small amounts of iron pyrites occur and the deposit is in every way similar to the surface croppings of some of the copper deposits of the district. There is little doubt that this deposit is the gossan or iron hat of a sulphide vein. The mechanical impurities in the ore are so finely divided that its quality can not be bettered by hand picking, and sulphur is present as a chemical detriment.

TITANIFEROUS IRON ORE OF IRON MOUNTAIN, WYOMING.[a]

By Sydney H. Ball.

INTRODUCTION.

In the fall of 1906 the writer visited Iron Mountain, Wyoming. Since the economic possibilities of the deposits there are awakening wide interest and since the descriptions already published are out of print or are difficult of access, a short description of this region may be of value. The following bibliography includes the principal articles relating to Iron Mountain:

Stansbury, Howard, Captain, Corps Topographical Engineers, U. S. Army. Exploration and survey of the valley of the Great Salt Lake of Utah, etc. Philadelphia, 1852, p. 266.

Hayden, F. V. First, Second, and Third Ann. Repts. U. S. Geol. and Geog. Survey Terr. (1867–1869), 1873, pp. 80–81.

——— Preliminary Rept. U. S. Geol. Survey of Wyoming and portions of contiguous territories (1870), 1871, p. 14.

King, Clarence. U. S. Geol. Explor. Fortieth Par., vol. 1, p. 27.

Hague, Arnold. Ibid., vol. 2, pp. 14–16.

Zirkel, F. Ibid., vol. 6, p. 107.

Knight, Wilbur C. Bull. 14, Exper. station, Laramie, Wyo., Univ. Wyoming, Oct., 1893, p. 177.

Kemp, J. F. Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, p. 420.

Lindgren, Waldemar. Science, new series, vol. 16, 1902, pp. 984–985.

Kemp, J. F. School of Mines Quarterly, vol. 20, 1900, pp. 352–355.

Hill, B. F. School of Mines Quarterly, vol. 20, 1900, p. 364.

The conclusions herein expressed are in all essential particulars in accord with those set forth by Mr. Lindgren and by Professor Kemp.

GEOGRAPHY AND HISTORY.

Iron Mountain is in southeastern Wyoming in the east-central part of Albany County. It lies 8 miles west of Iron Mountain station, on the Colorado and Southern Railroad, and approximately 40 miles northwest of Cheyenne, Wyo. The deposit, which is in the Laramie

[a] After this note had been partly written in the field an article by Prof. J. F. Kemp in the Zeitschrift für praktische Geologie (vol. 13, pp. 71–80) came to the writer's attention. Professor Kemp, in addition to describing Iron Mountain, mentions the occurrence of similar iron ore in dikes at the Shanton ranch 4 miles southwest of Iron Mountain.

foothills 1 mile from the eastern border of the pre-Cambrian complex, in secs. 22, 23, 26, and 27, T. 19 N., R. 71 W., is reached from Iron Mountain station by a wagon road. Chugwater Creek passes in a gorge through the iron ore body.

Beside this main body of the magnetic iron minor masses occur in the pre-Cambrian rocks in a belt which is reported to extend from Horse Creek to Sibylee Creek, a distance of 20 miles. This belt, which courses a little east of north and west of south, is in places 5 miles wide.

Iron Mountain, a rugged ridge from 300 to 600 feet wide and $1\frac{1}{4}$ miles long, rises sharply from the anorthosite hills to the east and the rolling pre-Cambrian uplands to the west. Its ragged top presents a marked contrast to the regular hogbacks of the foothill sedimentary rocks.

The iron was first noticed by Capt. Howard Stansbury, U. S. Army, on September 30, 1850, when he was in camp on the banks of Chugwater Creek, on his way to Great Salt Lake. He found along the banks of the stream and in the adjacent hills "immense numbers of rounded black nodules of magnetic iron ore, which seemed of unusual richness." [a] In 1866 F. V. Hayden visited the mountain itself. The greater portion of the main deposit passed into the hands of the Union Pacific Railroad as a part of the land granted to it in 1862. In 1872 a wagon road was built to the deposit, prospectors rushed in, and the whole countryside was staked. In the following year a post-office, Iron Mountain, was established at the base of the iron ridge, but was abandoned in 1874. Eight or ten years ago the Colorado Fuel and Iron Company employed 15 teams for several months in hauling ore from the mountains to the railroad, whence it was shipped to their smelters at Pueblo. The work was suddenly abandoned, however, although the same company is reported to have made a small shipment four years ago. In 1905 and 1906 the main ore body was visited by a number of surveying corps, and the Colorado Land and Iron Company is said to have located claims between Chugwater and Sibylee creeks.

GEOLOGY.

The pre-Cambrian complex near the large dike of iron ore at Iron Mountain consists of three granular igneous rocks—an anorthosite,[b] the iron ore, and a granite. The anorthosite is the oldest of these and is cut by dikes and lenticular masses of iron ore and granite. The relative ages of the iron ore and granite was not certainly determined, since exposures are poor where the two rocks are close together. All the available evidence, however, indicates that the iron ore is older than the granite.

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[a] Stansbury, Howard, Exploration and survey of the valley of the Great Salt Lake of Utah, Washington, D. C., March, 1851.

[b] Anorthosite is a granular, wholly crystalline igneous rock, composed essentially of striated lime-soda feldspar, usually labradorite.

The anorthosite is a bluish to medium-gray holocrystalline rock of medium to coarse grain. It is composed almost wholly of gray feldspar, which in some places shows a feeble play of blue colors. Large flat crystals (phenocrysts) of gray feldspar, from 2 to 3 inches long and one-quarter to one-half inch thick, occur in some portions of the rock. Irregular masses of the rock are made up wholly of a granular aggregate of these large crystals. Immediately east of the iron ore dike, for a distance of 6 feet from the ore, the anorthosite contains crystals of magnetite (probably titaniferous) from one-eighth to 3 inches in diameter. In other parts of the mass, also, magnetite is abundant. Biotite and greenish black pyroxene are likewise visible to the naked eye in some portions of the anorthosite. As seen under the microscope the anorthosite is a fine to coarse-grained evenly granular igneous rock, composed predominantly of labradorite (plagioclase feldspar). Biotite is everywhere present, while titaniferous iron ore, olivine, a monoclinic pyroxene, occur in some specimens, and a single thin section contains apatite and a little quartz. The secondary minerals include chlorite, serpentine, calcite, and sericite.

The mass of iron ore is an igneous dike 1¼ miles long and 40 feet to 300 feet wide, the greatest observed width being at the point where Chugwater Creek cuts through the mass. The dike trends east of north; most of it lies north of the creek. It widens and contracts rather abruptly throughout its course. Toward the north it gradually narrows and finally disappears while 300 feet south of Chugwater Creek it narrows slightly and then abruptly ends. At several places it is almost cut in two by wedgelike masses of granite, but throughout practically its whole length it is bordered by anorthosite. The contact between the anorthosite and the ore, where exposed, is sharp, neither rock having undergone important gradational changes. A second dike of iron ore is exposed 300 feet downstream (east), on the south side of Chugwater Creek. This dike varies in width from 6 to 20 feet and is clearly intrusive in the anorthosite, with which it has sharp contacts. About one-eighth of a mile southeast of the south end of the main mass is a third dike of iron ore in anorthosite. The trend of this dike, which is 300 feet long and from 10 to 30 feet wide, is approximately parallel to that of the main mass. Several small magnetite dikes that are from 10 to 50 feet long and have maximum widths of 3 feet lie east of this mass, in parallel alignment.

The iron ore is a black, granular, holocrystalline igneous rock, with constituent grains varying from one-eighth to one-half inch in diameter. It has a metallic or submetallic luster. Changes in granularity occur in irregular masses or along well-defined parallel planes. In consequence of this distribution the rock has at some places an original gneissic structure. The greater portion of the iron is free from

mechanical impurities, but biotite, olivine, and feldspar are sporadically distributed throughout its mass. Olivine is particularly abundant in portions of the small dike 300 feet east of the main mass. The iron ore is cut by rather closely spaced joints and by slickensided fracture planes. In consequence, the outcrop is angular, and its surface is littered with square blocks broken from the ore in place.

Weathering has broken down the iron ore mechanically and produced some chemical changes. Many weathered surfaces are pitted by reason of the complete removal of olivine and feldspar grains and the partial removal of biotite. On joint surfaces and along other fractures, limonite and less frequently hematite has been formed from the magnetite by percolating waters.

As seen under the microscope the ore in some specimens consists principally of titaniferous iron with a little spinel. Other thin sections show considerable olivine, while biotite and labradorite are present in many specimens and in a single section a crystal of what appears to be brown hornblende was noted.

Analyses of the iron ore are given in the following table:

Analyses of iron ore from Iron Mountain, Wyoming.

	A.	B.	C.	D.	E.	F.[a]	G.
Fe_2O_3	....	45.03	....	48.97	....	47.21	83.43
FeO	....	17.96	....	24.55	....	25.80	....
SiO_2	....	.76	....	[b] 2.15	....	1.21	1.64
TiO_2	[c] 20.68	23.49	23.32	23.18	49.47	22.43	14.06
Al_2O_3	....	3.98	....	....	....	....	....
Cr_2O_3	.16	2.45	....	....	....	....	....
Cr	.11	....	....	....	....	....	....
MnO_2	....	1.53	....	....	....	....	1.14
CaO	....	1.11	....	....	....	....	.22
ZnO	....	.47	....	....	....	....	....
MgO	....	1.56	....	....	....	....	....
S	.04	1.44	....	.03	....	1.14	.03
P	[d].011	Trace.	....	....	....	....	.036
Total	....	99.78	....	98.88	....	....	100.556
Metallic iron	49.66	45.49	50.83	53.33	34.29	....	58.40

[a] Other constituents not tried for. [b] Insoluble residue in acid. [c] Ti 12.42. [d] P_2O_5 .026.

A. Average sample across width of dike on north side of Chugwater Creek. Analysis by Dr. Eugene C. Sullivan.
B. Analysis by J. P. Carson, Fourth Ann. Rept. U. S. Geol. Survey Terr., Hayden, Washington, D. C., 1871, p. 14.
C. Analysis by Prof. O. D. Allen, U. S. Geol. Explor. 40th Par., vol. 2, p. 14.
D. Analysis by Professor Richards, Mass. Inst. Technology, ibid, p. 15.
E. Analysis by Prof. R. W. Woodward, ibid, p. 14.
F. Analysis by W. C. Knight, Univ. Wyoming, Bull. Wyoming Experimental Station, No. 14, p. 177, 1893.
G. Sample of Iron Mountain ore smelted at Portland Exposition, loaned by Dr. D. T. Day. Analysis by Columbia Engineering Works, Portland, Oreg.

The iron content is fairly high, averaging perhaps 50 per cent, and the most notable feature of the ore is its high titanium content. Of the injurious constituents besides titanium, the sulphur in three analyses is low and in two others high, while phosphorus in the three analyses in which it was determined is below the Bessemer limit.

The iron ore is younger than the anorthosite, but since each is massive no orogenic movements of importance separated the two intrusions. The writer considers the iron ore and the anorthosite differentiation products of a common magma, the iron ore having been intruded into the anorthosite after that rock had completely solidified. The relationship of the two rocks is shown not only by their close association, but also by the presence in each of similar minerals, the two differing in the proportion rather than in the kind of minerals composing them. Iron ore is locally abundant in the anorthosite near the iron-ore lens, while feldspar occurs sparingly in the iron ore, and biotite and olivine are present in each. Chemically the monoclinic pyroxene of the anorthosite and the monoclinic hornblende of the iron ore probably approximately balance one another. Apatite, present in the anorthosite, was not observed in the iron ore, although the phosphorus determined in two analyses of the ore probably indicates its presence. The spinel of the ore is, then, the only mineral not common to both rocks. Spinel has, however, been found in rocks rather similar to the anorthosite in composition from other regions.

The loose masses of iron ore broken off from the main mass have already been mentioned. Chugwater Creek has carried these downstream and rounded them, and it was these rounded-ore pebbles that first attracted the notice of the early explorers. Where the Colorado and Southern Railroad crosses the creek, 10 miles from the iron-ore body, the pebbles are 1 inch in diameter and beautifully rounded. Much larger pebbles of iron ore, some 6 inches in diameter, occur in the Pleistocene terrace deposits that characterize this portion of the front of the Rocky Mountains. The difference in the size of the bowlders in the two stream deposits rudely indicates the differences between the transporting power of the stream depositing them.

Apparently the youngest of the pre-Cambrian rocks is a granite. This certainly occurs in dikes in the anorthosite and probably cuts the iron ore as well. It is a pinkish-gray, medium-grained biotite granite, some specimens of which contain pink porphyritic feldspars one-half inch long. It grades into and is cut by a biotite pegmatite. Magnetite is at some places present in the pegmatite, and at such places the magnetite, which distinctly belongs to the pegmatite period of intrusion, impregnates the immediately surrounding granite. Under the microscope the granite is seen to be an even granular rock rich in microcline and, for a granite, rather poor in quartz.

The presence of an iron ore as a visible constituent of the three igneous rocks of this area and as the dominant constituent of one of them is worthy of note. This, then, may be considered a pre-Cambrian metallographic province,[a] characterized by abundant magnetite.

[a] Spurr, J. E., Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 276.

COMMERCIAL POSSIBILITIES OF THE ORE.

The immense ore body at Iron Mountain, extending 1¼ miles with an average width of perhaps 175 feet, is, like granite, an igneous rock and is likely to hold its width for a great depth from the surface or even, perhaps, to thicken somewhat with increasing depths. Chugwater Creek has cut a deep channel through the ore, and in consequence conditions are favorable for open-pit mining. A narrow-gage railroad could be built from the Colorado and Southern Railroad at Iron Mountain to the deposit or, at considerably greater expense, a broad-gage road could be constructed. The cost of fuel in this portion of Wyoming is surprisingly high in view of the proximity of coal mines. Chugwater Creek is too small a stream to produce cheap electric power, which, however, might be obtained from some of the Colorado power companies.

In the present day smelter practice iron ores with such high titanium content are practically valueless, but progress is being made in the treatment of these ores, and at some future time the deposit at Iron Mountain will doubtless be of great commercial importance.

Titanium is very undesirable in iron ores because of its refractory character, its ores being practically unreducible at the temperature of blast or open-hearth furnaces. As a constituent of iron and steel, however, titanium increases toughness and tensile strength. In consequence the production of high-grade iron from titaniferous ores is under some conditions profitable. Titaniferous iron ores have been successfully smelted in Sweden, England, and the United States, but even in Sweden the cost was so great that the annual output has gradually diminished, until, in 1892, the Taberg mine produced but 40 tons of pig as against 9,204 tons in 1875.[a] Mr. A. J. Rossi[b] in the early nineties successfully smelted ores with 20 per cent TiO_2 in smelters of 3-ton daily capacity. Thirteen years after the publication of his article, however, no attempt has been made to verify his results on a commercial scale.

Some attempts to separate the nontitaniferous from the titaniferous ores by magnetic processes have been partially successful. The waste of iron, however, since titaniferous iron itself carries considerable iron, is so great that the process is commercially a failure. This process requires fine crushing, and hence, subsequently, briquetting.

[a] Hulst, N. P., Proc. Lake Superior Mining Institute, vol. 10, p. 40.
[b] Trans. Am. Inst. Min. Eng., vol. 21, pp. 832-867, 1893.

The most promising method of treating titaniferous iron ores is reduction in the electric furnace. Experimentally the process is successful, and its commercial application is wholly a question of cost. Concerning this F. W. Harbord [a] states:

Pig iron can be produced on a commercial scale at a price to compete with the blast furnace only when electric energy is very cheap and fuel very dear. On the basis taken in this report with electric energy at $10 per estimated horsepower year and coke at $7 per ton, the cost of production is approximately the same as the cost of producing pig iron in a modern blast furnace.

Under ordinary conditions where blast furnaces are an established industry, electric smelting can not compete, but in special cases where ample water power is available, and blast-furnace coke is not readily obtainable, electric smelting may be commercially successful.

These conclusions apply to nontitaniferous ores, although Dr. Eugene Haanel [b] says:

The experiment made with a titaniferous iron ore containing 17.82 per cent of titanic acid permits the conclusion that titaniferous iron ores up to perhaps 5 per cent titanic acid can be successfully treated by the electric process.

In 1905–6 experiments in smelting magnetic iron ores electrically were carried on under the direction of Dr. David T. Day of the U. S. Geological Survey, at Portland, Oreg. In the course of the experiments cast iron of good quality was obtained from the titaniferous ores of Iron Mountain, Wyoming. An analysis of the impurities in this iron is given below:

Impurities in iron produced from titaniferous ores of Iron Mountain, Wyoming.

Silicon	0.93
Manganese	None.
Phosphorus	.074
Sulphur	.005
Total carbon	4.3
Titanium	.53
Chromium	.09

Doctor Day states that 3,760 kilowatt hours were used on the average in smelting a ton of 2,000 pounds of pig iron produced, the total charge averaging approximately two of the Wyoming iron to one of briquettes made of Pacific coast magnetite sands. During a run of 2,583 pounds of iron, 205 pounds of graphite electrode were consumed.

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[a] Rept. of Commission appointed to investigate the different electro-thermic processes for the smelting of iron ores and the making of steel in operation in Europe: Dept. of the Interior, Ottawa, 1900, pp. 115–116.

[b] Prel. rept. on experiments made at Sault Ste. Marie, Ontario, under government auspices, in the smelting of Canadian iron ores by the electric-thermic process, Dept. of Interior, Ottawa, 1906, p. 23.

SURVEY PUBLICATIONS ON IRON AND MANGANESE ORES.

A number of the principal papers on iron and manganese ores published by the United States Geological Survey or by members of its staff are listed below:

Barnes, P. The present technical condition of the steel industry of the United States. Bulletin No. 25. 85 pp. 1885. (Out of print.)

Bayley, W. S. The Menominee iron-bearing district of Michigan. Monograph XLVI. 513 pp. 1904.

Birkinbine, J. American blast-furnace progress. In Mineral Resources U. S. for 1883–84, pp. 290–311. 1885.

——— The iron ores east of the Mississippi River. In Mineral Resources U. S. for 1886, pp. 39–98. 1887.

——— The production of iron ores in various parts of the world. In Sixteenth Ann. Rept., pt. 3, pp. 21–218. 1894.

——— Iron ores. In Nineteenth Ann. Rept., pt. 6, pp. 23–63. 1898.

——— Manganese ores. In Nineteenth Ann. Rept., pt. 6, pp. 91–125. 1898.

Boutwell, J. M. Iron ores in the Uinta Mountains, Utah. In Bulletin No. 225, pp. 221–228. 1904.

Burchard, E. F. The iron ores of the Brookwood district, Alabama. In Bulletin No. 260, pp. 321–334. 1905.

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ALUMINUM AND BAUXITE.

The known bauxite districts of the United States were examined and described in detail some years ago by C. W. Hayes, and so far no large extension of the industry has taken place outside the area covered by his work. That such an extension is possible, however, is evidenced by discoveries which have been made during the last three years. Bauxite deposits of more or less promise have been uncovered in the vicinity of Fort Payne, Ala., as well as in Tennessee, Virginia, and Pennsylvania. In all these places the bauxite is associated with Cambrian or Cambro-Ordovician rocks—the Knox or Shenandoah limestone of the valley regions—so that the newly found ore bodies correspond closely to the type described by Hayes from Alabama and Georgia.

THE GILA RIVER ALUM DEPOSITS.

By C. W. Hayes.

INTRODUCTION.

The deposits described in the following pages occupy a small arid region in Grant County, N. Mex., on both sides of Gila River. This area embraces portions of secs. 19, 20, 29, and 30, T. 13 S., R. 13 W. It is about 27 miles due north of Silver City and is at present accessible from that point by a wagon road which reaches Gila River at Lyons Hot Springs, about 6 miles above, and thence follows the river down to the mouth of Alum Creek.

The locality was visited in 1893 by W. P. Blake, who published a brief account of the deposits in the Transactions of the American Institute of Mining Engineers, vol. 24, 1894. A somewhat more extended report by Professor Blake is contained in a pamphlet published privately in 1893 by A. T. Johnston, owner of the property. So far as known these are the only publications containing any first-hand information concerning the deposits, though they have been known to prospectors and ranchers for many years. Some material from the deposits was analyzed by F. W. Clarke in the laboratory of the United States Geological Survey in 1884, and the results of the analysis were published in Bulletin No. 9, though without further information concerning the deposits than their general location.

Professor Blake devoted parts of only two days to the examination of these deposits, and the actual time spent on them by the writer was less than three days, so that the geologic work thus far done must be regarded as purely of a reconnaissance character and the conclusions as preliminary and tentative.

TOPOGRAPHIC RELATIONS.

The alum deposits occupy a nearly circular depression below the general level of the volcanic plateau. Gila River cuts through the northern edge of this depression, and Alum Creek intersects its eastern portion from south to north. The elevation of the river is about 4,000 feet above sea level; the rim of the basin is between 2,000 and 3,000 feet higher. The inner slopes of the basin rim are very steep and generally surmounted by basaltic cliffs. Except where the river enters and leaves the basin and at one point where Alum Creek heads against the upper branches of Copperas Creek, the rim is practically continuous. The latter point has been selected for a trail which by way of Copperas Creek and the Sapio affords the most direct approach to the basin.

Within this basin is a group of hills, the highest of which, Alunogen Ridge, rises from 1,000 to 1,200 feet above the river. These hills are separated by Alum Creek and its branches into three groups. The largest group, with Alunogen Ridge along its southern border, lies west of Alum Creek, between the west fork and the Gila. On the west it is separated by a deep depression from the western rim of the basin. East of Alum Creek is a smaller group of hills, culminating in a sharp peak something over 800 feet above the river and separated from the east rim of the basin by a shallow depression. Between the two main forks of Alum Creek is a third and smaller group, forming the point of a spur from the southern rim of the basin. This group consists of a series of pinnacles and isolated buttes with nearly vertical sides. North of the rim a fourth group of hills rises abruptly from the slope of the basin.

These hills within the basin are entirely distinct in form from any other topographic features of the region. They are characterized by great numbers of pinnacles and isolated buttes rising abruptly from steep talus slopes. The cliffs are weathered into innumerable intricate and fantastic forms and in many places are covered with heavy masses of incrustations. Even more striking than their peculiar form is their varied and brilliant coloring, which forms a strong contrast with the somber greenish gray and black of the surrounding basaltic basin rim. The prevailing colors are white and red, with all shades of pink, yellow, and green.

GEOLOGIC RELATIONS.

This portion of New Mexico is occupied wholly by igneous rocks, the nearest sedimentary beds being Carboniferous limestone in the vicinity of Santa Rita, 20 miles to the southeast. The canyon of Gila River exhibits a great series of lava flows alternating with volcanic tuffs and breccias. At Lyons Hot Springs the lower 200 or 300 feet consists of generally vertical cliffs of light-gray rhyolite. Above this is a great thickness of andesitic breccia, containing large fragments of basalt. This resembles a very coarse conglomerate and may be in part water-laid. Between Lyons Hot Springs and Alum Creek the rhyolite and the overlying breccia disappear and are replaced by a series of basalt sheets which extend from the level of the river to the summit of the plateau, 3,000 feet or more above.

The rocks which are of chief importance in the present connection, and which occupy the greater part of the topographic depression described above, are andesitic breccias. Although this rock presents considerable variation in appearance, its different phases grade into each other and there is nowhere any difficulty in distinguishing it from the surrounding basalt. Its breccia character is generally evident to the unaided eye, the rocks being made up of angular fragments embedded in a fine-grained groundmass. The angular inclusions are in the main similar to the matrix in composition and structure, though somewhat finer grained. Here and there they are composed of an entirely distinct type of rock. This is most common near the contact with the basalt, where fragments of that rock are in places abundant. Considerable portions of the rock, however, show no breccia character.

This andesitic volcanic breccia will be referred to as the alum rock.

DISTRIBUTION AND RELATIONS TO BASALT.

The distribution of the alum rock is shown on the accompanying sketch map (fig. 6). Owing to lack of time, contacts were traced in detail at only a few points, and they will doubtless be materially modified by further study. In a general way, however, the map shows the more important facts of distribution.

It will be seen that the main mass of the alum rock occupies a nearly circular area, lying for the most part south of Gila River and west of Alum Creek. About the margins of this main mass are smaller areas occupied by the alum rock, the largest being north of the river and several small ones lying in the upper basin of Alum Creek. It is possible that the mass north of Gila River is continuous with the main mass to the south, though more probably it is entirely distinct. Doubtless there are other small masses in addition to those shown on the map.

The relations of the alum rock to the adjacent basalt are well shown on the steep eastern slope of Alum Canyon. The contact here extends about N. 60° E., and is marked by a deep, narrow ravine. To the north the alum rock forms a series of pinnacles and in places the original outer surface of the mass is shown, the basalt having been the more easily eroded of the two rocks. At this point the contact is vertical and the alum rock contains numerous fragments of the basalt up to several feet in diameter. The relations here indicate clearly that the alum rock has broken through the basalt in the form of an igneous

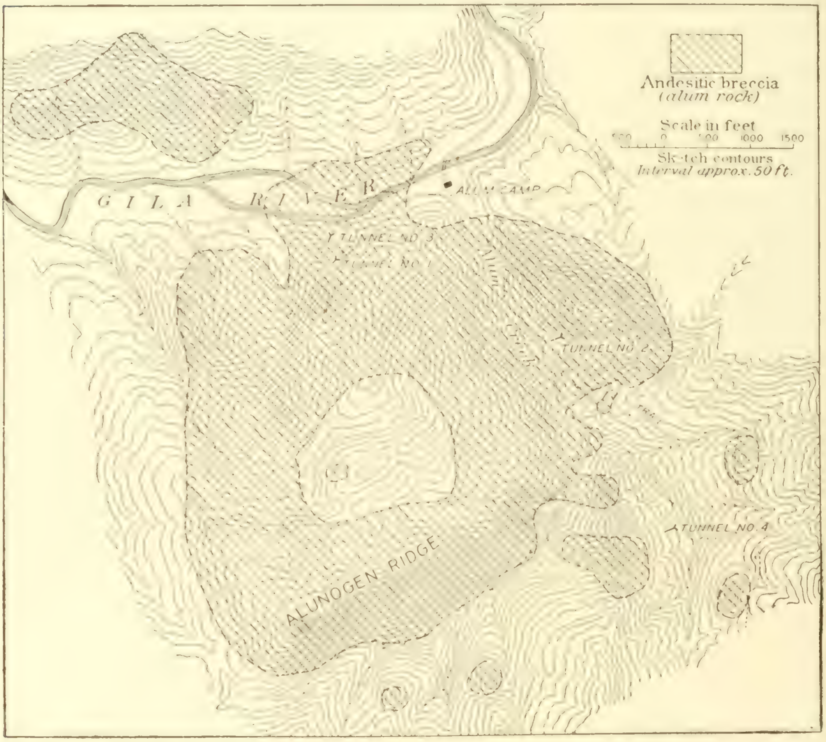

FIG. 6.—Sketch map of Gila River alum deposits, based on claim map prepared by R. L. Powell, United States deputy surveyor.

intrusion, probably with intense explosive violence. The basalt shows a foliation or platy structure parallel to the contact and extending several feet from it. Within this zone it is deeply weathered to a greenish clay, though the structure of the rock remains.

Similar relations between the alum rock and the basalt were observed at several other points, notably on the point of the ridge between the forks of Alum Creek and along the western margin of the main mass. In every place where the contact was well exposed it was either vertical or at a high angle, and the alum rock contained fragments of the basalt. One peculiar feature shown by the map is

the large body of basalt entirely surrounded by the alum rock, near the center of the main mass. Although its relations are obscure, this appears to be merely a large inclusion, broken off from some underlying basalt sheet and floated up to its present position by the intruded mass.

ALUM ROCK.

The most striking peculiarity of the alum rock is its extreme alteration. This is evident to the unaided eye and even more so when the rock is examined under the microscope. Careful search failed to reveal at any point within the Alum Creek basin a trace of the unaltered breccia for determination of its original character. Where exposed to leaching, as in the upper parts of pinnacles and cliffs, the rock is invariably porous, giving a hollow sound under the hammer. It is evident that a considerable part of its substance has been removed in solution.

The least altered phase of the alum rock is seen in tunnel No. 2, which is driven about 180 feet into the face of the cliff on the east side of Alum Canyon. The rock is fine grained an l was originally composed of minute crystals of plagioclase feldspar embedded in a glassy groundmass. Both feldspar crystals and matrix are much altered, only the outlines of the former remaining. There are also abundant very fine, dustlike particles of pyrite. Near the face of the cliff the rock is white and chalky, but a few feet in from the face it has a white chalky base more or less mottled with bluish-gray patches in which the alteration is evidently less complete. A rock originally very similar to that in tunnel No. 2 forms the point of the spur between the forks of Alum Creek.

The composition of the various phases of the alum rock is shown in the accompanying analyses.

Analyses of alum rock from Gila River, New Mexico.

[W. T. Schaller, analyst.]

	A.	B.	C.	D.
Soluble in water:				
$Al_2O_3+Fe_2O_3$	0.51	0.22	....	....
SO_3	1.83	1.64	....	....
Insoluble in water:				
SiO_2	55.76	50.45	57.25	83.51
Al_2O_3 ($+TiO_2$)	20.64	18.61	32.27	5.55
Fe_2O_3 (total iron)	4.16	3.79	Trace.	Trace.
Loss on ignition	18.07	23.85	12.07	7.38
Ignited residue insoluble in water	81.19	76.16	88.00	91.69

A. Alum rock, white, mottled bluish gray, from tunnel No. 2, 50 feet from mouth of tunnel.
B. Alum rock, disintegrated, from dump of tunnel No. 2.
C. Alum rock, white, chalky, from point of ridge between forks of Alum Creek.
D. Alum rock, pinkish white, porous, from summit of Alunogen Ridge.

Of the four samples analyzed A and B represent practically the same material, the only difference being that the material on the

dump has been thoroughly disintegrated by exposure to the weather for thirteen years. It contains nearly 6 per cent more water and less silica and alumina than the tunnel rock, though the ratio of silica to alumina is practically the same in both. In C the ratio of silica to alumina is lowest and the material contains practically no iron. D is highly siliceous, as was to be expected from its appearance and its exposed position.

INCRUSTATIONS.

Two forms of incrustations having entirely different chemical composition are common in association with the alum rock wherever the conditions are favorable for their accumulation.

Upon the sides of the cliffs, particularly where they overhang or are undercut and pitted by erosion and afford some protection from rain, are extensive deposits of material, evidently leached out of the adjacent rock and deposited from solution. These incrustations vary in thickness from a few inches to 3 or 4 feet. The outer surface has a fluted appearance, resembling some stalactitic cave deposits. It is generally yellowish white in color and is fairly hard, with a porous, cellular structure. Within this outer crust the material is much softer and in many places occurs as a perfectly white powder. This incrustation consists of the hydrated sulphate of aluminum, alunogen. The white powdery material is very pure and has practically the theoretical composition of alunogen; the outer crust contains a slight amount of impurities and less than the theoretical amount of water.

The following analyses give the composition of this incrustation:

Analyses of alunogen from Gila River, New Mexico.

	A.	B.	C.
Al_2O_3	16.29	15.52	15.3
SO_3	36.93	34.43	36.0
H_2O	46.45	42.56	48.7
Insoluble residue		7.62	
	99.67	100.13	100.0

A. Analyst, George H. Corey. Carefully selected crystals.
B. Analyst, F. W. Clarke. Pinkish crusts. Bull. U. S. Geol. Survey No. 9, 1884, p. 13.
C. Theoretical composition of alunogen—$Al_2(SO_4)_3+18\ H_2O$.

The second form of incrustation is most abundant on the walls of the tunnels which have been driven into the alum rock, particularly in No. 2. This tunnel was driven in 1893, and since that time its walls have become coated with a heavy incrustation from 3 to 6 inches thick, consisting of halotrichite, a silky fibrous mineral closely resembling asbestos in appearance. It has a very pale greenish color and a strongly astringent taste. The outer exposed surface of the incrus-

tation has generally lost its fibrous structure, becoming compact and assuming a yellowish color. Although the incrustation may be several inches thick, the individual fibers are rarely more than a third or a half of an inch in length, the crust being made up of successive layers of short crystals. Each layer probably represents the growth of a single season during which the supply of percolating water was relatively abundant. The layers of crystals are in places separated by a very thin film of the rock which has been split off by the growth of a subsequent layer of crystals.

The chemical composition of this fibrous halotrichite is shown below.

Analyses of halotrichite from Gila River, New Mexico.

	A.	B.	C.
FeO	7.94	13.59	7.8
Al_2O_3	11.77	7.27	11.0
SO_3	35.25	37.19	34.5
H_2O	45.09	40.62	46.7
Insoluble		.50	
	100.05	99.17	100

A. Analyst, W. T. Schaller. Carefully selected fibrous crystals from tunnel No. 2.
B. Analyst, F. W. Clarke. "Fibrous mineral of silky luster." Bull. U. S. Geol. Survey No. 9, 1884. Contains a trace of Fe_2O_3.
C. Theoretical composition of halotrichite—$FeSO_4+Al_2(SO4)_3+24H_2O$.

As shown in the foregoing analyses, the halotrichite is the double sulphate of aluminum and iron, and the alunogen is the sulphate of aluminum and is free from iron except as a minor impurity. The relations of the two minerals may be explained as follows:

As a result of chemical reactions within the alum rock the double sulphate, halotrichite, is formed. This is carried to the surface in solution by the slow capillary circulation and on the evaporation of the solvent water is deposited as a crystalline incrustation. Wherever water subsequently gains access to this deposit it is redissolved and carried downward. This solution, however, particularly when it forms a thin film trickling down the face of a cliff, affords abundant opportunity for oxidation and the iron is converted from the ferrous to the ferric state and thereby becomes insoluble. It is deposited as ferric oxide, which accounts for the prevalence of red color in the rocks and soil, whereas the aluminum sulphate, unaffected by the oxidizing conditions, remains in solution and either passes off with the surface waters or by the evaporation of the water is deposited in stalactitic forms and incrustations upon the cliffs.

In the report already cited, Blake suggests two methods by which the chemical reactions necessary for the formation of sulphates within the alum rock may be produced, namely, (1) the oxidation of the contained pyrite with the production of free sulphuric acid, and (2) the

ascent of acid solutions and gases from a deep source with the resulting solfataric action which often characterizes the final phases of volcanic activity.

The andesitic breccia generally contains fine disseminated grains of pyrite, probably enough to produce by their oxidation the necessary sulphuric acid for all the sulphates present. So far as observed, however, the pyrite in the alum rock is perfectly fresh and unoxidized. Further, the mineral halotrichite, which seems to have been the form of sulphate first formed, is extremely unstable under oxidizing conditions, the iron passing readily to the ferric condition and becoming at once insoluble. Hence halotrichite could not be formed under conditions favorable for the oxidation of pyrite. If the pyrite had been the source of the sulphuric acid the mineral produced would have been one of the more stable sulphates.

Another source for the sulphuric acid must therefore be sought, and its volcanic origin is at once suggested. As has been shown, the alum rock was originally an andesitic breccia which filled the neck of a volcano. This volcanic neck cuts through and is therefore later than the great basaltic lava sheets which occupy so much of this region. It may very easily have been active in late Tertiary or Quaternary time and have been, in part, at least, the source of the great beds of tuff and breccia which fill an old valley to the north, now in part reexcavated by Gila River. The brecciated character of the material filling the volcanic conduit permitted the easy ascent and circulation of gases and solutions from great depths, and if these contained free sulphuric acid they would be entirely competent to produce the alteration observed in the breccia and the sulphates which it contains. The alteration is confined almost entirely to the breccia within the volcanic conduit, generally extending only a short distance into the surrounding basalt. The alteration of the basalt is most extensive where it was most fractured by the intrusion, as in the vicinity of the numerous small intrusions of breccia southeast of the main mass. As the basalt consisted largely of ferromagnesian minerals, it yielded under the action of the acid solutions chiefly hydrated magnesian silicates and gypsum, the latter being rather abundant as selenite crystals in the residual greenish clay.

The determination of the agent producing the chemical changes in the breccia has more than a theoretical scientific interest. If these changes were due to the acid produced by the oxidation of pyrite, they would not be expected to extend beyond the relatively shallow zone of oxidation. If, on the other hand, they are due to ascending acid solutions, they may be expected to extend to much greater depths.

It is probable that the fumarolic activity to which the chemical changes appear to be due has entirely ceased in this particular volcanic neck. No thermal springs and no emanations of acid gases

have been observed within the area of the alum basin. A few miles distant up Gila Canyon hot springs occur at three separate points. No analyses of the waters from these springs are available, but they show no evidence of being highly mineralized. The only deposit at these vents is a very slight incrustation of the rocks over which the waters flow, and this is apparently silica. Their presence, therefore, near the breccia-filled volcanic vent is probably without significance.

UTILIZATION.

In his paper on these deposits Blake states that the residual rock from which the soluble sulphates have been leached consists essentially of hydrated aluminum oxide or bauxite. The analyses given on page 219 do not indicate the presence of free aluminum oxide, but, on the contrary, show that the residual rock is essentially the silicate of aluminum, having approximately the composition of kaolin. The value of the deposits will therefore depend on the utilization of the soluble sulphates which they contain. The present surface accumulations of alunogen, though probably amounting to many hundreds or, more probably, thousands of tons, represent but an insignificant quantity compared with the sulphates still in the rock. Wherever observed the rock is highly porous, and the extent of its porosity represents the amount of material removed. In the higher and more exposed ledges the rock is thoroughly leached and will yield nothing more. At lower levels the rock still contains a part of its soluble constituents, which are coming to the surface by the capillary circulation of surface waters. The extent of this loss is shown in tunnel No. 2, where the average annual accumulation of halotrichite is about half an inch. No test has been made of the rock below drainage level, but it is probable that here, where there has been no opportunity for leaching, will be found the largest amount of soluble constituents.

Since this deposit presents so many unique characteristics, it is hazardous to venture a prediction as to its future utilization. New methods of mining and treatment must be devised to meet the peculiar conditions, and success will depend largely on the skill with which the problem is handled. That there exists here an almost unlimited supply of aluminum sulphate appears, however, certain, and in view of the rapidly growing demand for this substance in the arts, in sanitary engineering, and as a source of the metal, there is little question that the supply will in time be fully utilized. The essentials for such utilization appear to be transportation facilities and chemical engineering skill.

SURVEY PUBLICATIONS ON ALUMINUM ORES—BAUXITE, CRYOLITE, ETC.

The following reports published by the Survey contain data on the occurrence of aluminum ores and on the metallurgy and uses of aluminum:

Canby, H. S. The cryolite of Greenland. In Nineteenth Ann. Rept., pt. 6, pp. 615-617. 1898.

Hayes, C. W. Bauxite. In Mineral Resources U. S. for 1893, pp. 159-167. 1894.

——— The geological relations of the southern Appalachian bauxite deposits. In Trans. Am. Inst. Min. Eng., vol. 24, pp. 243-254. 1895.

——— Bauxite. In Sixteenth Ann. Rept., pt. 3, pp. 547-597. 1895.

——— The Arkansas bauxite deposits. In Twenty-first Ann. Rept., pt. 3, pp. 435-472. 1901.

Schnatterbeck, C. C. Aluminum and bauxite [in 1904]. In Mineral Resources U. S. for 1904, pp. 285-294. 1905.

Spurr, J. E. Alum deposits near Silver Peak, Esmeralda County, Nev. In Bulletin No. 225, pp. 501-502. 1904.

Struthers, J. Aluminum and bauxite [in 1903]. In Mineral Resources U. S. for 1903, pp. 265-280. 1904.

PORTLAND, NATURAL, AND PUZZOLAN CEMENTS.

PORTLAND CEMENT MATERIALS NEAR DUBUQUE, IOWA.

By Ernest F. Burchard.

INTRODUCTION.

In the summer of 1905 a detailed geologic survey of the Lancaster quadrangle, lying mainly in Wisconsin and Iowa, was made by J. R. Banister, A. W. Lewis, and the writer. During the survey particular attention was given to the investigation of certain natural resources of the district, among them the beds of limestone and clay, with a view to ascertaining their value for making Portland cement. The Iowa Geological Survey cooperated in the work to the extent of making chemical analyses of some of the materials collected. This analytical work, carried on under the supervision of S. W. Beyer at the Iowa College of Agriculture and Mechanic Arts, at Ames, is still unfinished. It is planned further to ascertain the proportions in which the materials must be combined in order to produce the best cement, to burn the material on a small scale, and to make tests for fineness and tensile strength of the resulting cement as soon as the necessary machinery is installed in the college laboratories. In case these results are as favorable as there is reason to believe they will prove to be, the information should be of considerable importance, for the district appears to be so situated as to need a cement plant.

The trade territory would be confined to the region west, north, and northeast of Dubuque, and would comprise a large part of the States of Iowa, Minnesota, and Wisconsin. A plant near Dubuque would at present have to meet competition from Mason City, Iowa; Hannibal, Mo.; and Dixon, Ill. Dubuque has the advantage of cheap water transportation, besides four direct rail lines to the north, and might fairly be able to control the trade along the river up to and including St. Paul and Minneapolis.

MAPS AND OTHER PUBLICATIONS.

Dubuque, Iowa, is on the south edge of the Lancaster quadrangle, which extends northward about 35 miles from latitude 42° 30′. East and west of Dubuque the quadrangle extends, respectively, 9 and 17 miles. The United States Geological Survey has issued topographic and geologic maps of this quadrangle which are together available in the geologic folio of the Lancaster-Mineral Point area (folio No. 145, Geologic Atlas U. S., price 25 cents). The topographic maps are also issued separately and sold for 5 cents each. Other useful maps and discussions of the geology of the district have been issued by the State surveys, as follows:

CALVIN, SAMUEL, and BAIN, H. F. Geology of Dubuque County: Iowa Geol. Survey, vol. 10, 1900, pp. 379–622.

BEYER, S. W. Supplementary report on Portland cement materials in Iowa: Bull. Iowa Geol. Survey No. 3, 1906, 36 pp.

GRANT, U. S. Report on the lead and zinc deposits of southwestern Wisconsin, with atlas: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 14, 1906, 100 pp.

AGE AND DISTRIBUTION OF THE ROCKS.

The principal rocks exposed along Mississippi River and near the mouths of its tributaries between Dubuque, Iowa, and Cassville, Wis., together with their ages and essential features, are comprised in the following table:

Rocks exposed north of Dubuque, Iowa.

System.	Formation.	Character.	Thickness.
			Feet.
Quaternary		Loess	1–60
		Residual clay	1–15
Ordovician	Galena	Dolomite and chert	235
	Platteville	Limestone and shale	55
	St. Peter	Sandstone	70
	Prairie du Chien	Cherty magnesian limestone	1–40 exposed.

A few miles back from the river the Maquoketa shale and Niagara limestone are present in the section, above the Galena, but these rocks have no bearing on the present subject. The beds of particular importance are the limestone and shale of the Platteville, the basal Galena beds, and the residual clay and loess, all of which are exposed in the bluffs of the Mississippi River gorge between Dubuque and Cassville.

MANUFACTURING SITES.

Along the greater part of the river front between these cities the bluffs rise steeply to a height of 60 to 100 feet above the flood plain and then slope more gently to a total height of 150 to 200 feet above the river. On both sides of the river a railroad runs close to the base of

the bluff. In several lateral ravines and valleys large enough for mill sites the Platteville beds are favorably situated for quarrying, so that the broken rock may be loaded into a mill by gravity. Five such localities were sectioned and sampled in detail. In the order of their distances from Dubuque they are as follows: (1) Near Zollicoffer Lake, Peru Township, Iowa, in the SW. ¼ sec. 23, T. 90 N., R. 2 E.; (2) at Spechts Ferry, Iowa; (3) near Potosi Station, Wis., in the SE. ¼ sec. 4, T. 2 N., R. 3 W.; (4) about 1 mile above Waupeton, Iowa, in the NE. ¼ sec. 25, T. 91 N., R. 1 W.; (5) near McCartney, Wis., in sec. 4, T. 2 N., R. 4 W.

CHARACTER OF MATERIALS.

A generalized section of the Platteville includes the following divisions:

Generalized section of Platteville formation.

	Feet.
4. Limestone, principally in thin beds, and shale	10–15
3. Limestone, fine grained, brittle, and thin bedded	15–25
2. Limestone, magnesian, thick bedded	15–25
1. Shale, bluish, sandy in places	1– 5
	41–70

Nos. 3 and 4 of the above generalized section contain the purest limestone, but in places part of No. 2 also is found to contain less than 5 per cent of magnesium carbonate. The following table gives the stratigraphic details and the corresponding chemical analyses of the beds at two localities in Iowa:

Analyses of Platteville limestone and shale.

[Analyst, L. G. Michael, Iowa College of Agriculture and Mechanic Arts, Ames, Iowa.]

No.	Location and character of bed.	Thickness. Ft.	Thickness. in.	SiO_2.	$Fe_2O_3 + Al_2O_3$.	$CaCO_3$.	$MgCO_3$.	Alkalies, as K_2O.	SO_3.	Combined H_2O.	H_2O (moisture).
	Near Zollicoffer Lake, Peru Township, Iowa, sec. 33, T. 90 N., R. 2 E.										
	Limestone, becoming magnesian above.										
7	Limestone, subcrystalline, medium beds	2	6	8.28	4.67	80.14	2.37	....	2.60	2.17	0.13
6	Limestone, thin beds	5		3.26	.83	90.20	2.65	....	1.64	1.84	.06
5	Limestone, thin beds	5	10	4.54	2.54	86.33	3.54	....	.22	2.62	.08
4	Limestone, in heavy bed	1	4	3.85	6.03	84.16	1.93	....	.64	4.23	.03
3a	Limestone, thin bands interbedded with shale (No. 3)	2	3	....	....	....	....	....	....	....	....
3	Shale, exclusive of limestone bands (No. 3a)	5	10	50.22	9.08 + 12.45	13.83	2.96	5.23	1.16	3.81	1.71
2	Limestone, coarse grained	6		6.79	4.61	78.24	5.12	....	1.74	3.28	.04
1	Limestone, fine grained, thin beds, unexposed below	12		8.02	5.78	77.93	4.43	....	.22	3.18	.16
	Spechts Ferry, Iowa, sec. 5, T. 90 N., R. 2 E.										
	Limestone, becoming magnesian above	10		....	....	....	....	....	....	....	....
5	Limestone	10		5.74	6.69	83.56	.25	....	1.77	1.50	.19
4a	Limestone, thin bands interbedded with shale (No. 4)	2	8	11.24	6.31	78.51	.24	....	1.58	1.85	.10
4	Shale, exclusive of limestone bands (No. 4a)	6	9	49.32	8.30 + 20.16	9.52	3.21	4.68	Tr.	4.82	.72
3	Limestone, massive beds	20		10.71	6.69	78.67	.28	....	1.51	1.70	.15
2	Limestone, medium beds	5		7.94	12.05	73.38	3.52	....	1.69	1.40	.10
1	Limestone, thin beds	9		7.50	6.17	79.50	3.97	....	1.48	1.60	.15
	Limestone, heavy magnesian beds	7	6	....	....	....	....	....	....	....	....
	Sandstone.										

Sections made at the other three places are as follows:

Section of Platteville-Galena beds near Potosi Station, Wis.

	Ft.	in.
6. Limestone, fine grained, thin bedded (Galena)	12	0
5. Shale, including 2 feet 4 inches of interbedded limestone, total	7	10
4. Limestone, fine grained, thin bedded	3	6
3. Limestone, even grained, medium bedded	3	0
2. Limestone, crystalline, thin bedded	12	0
1. Limestone, fine grained, thin, wavy bedded (partly concealed)	18	0

Section of Platteville-Galena beds near Waupeton, Iowa.

	Ft.	in.
5. Limestone, subcrystalline, with carbonaceous shale partings (Galena)	12	0
4. Shale	0	4
3. Limestone, similar to No. 5	1	5
2. Shale, blue, including 7 inches of thin limestone partings, total	6	3
1. Limestone, heavy bedded	5	0

Section of Platteville-Galena beds near McCartney, Wis.

	Ft.	in.
6. Limestone, subcrystalline, with carbonaceous shale partings (Galena)	12	0
5. Shale, calcareous, including 6 inches of thin limestone partings, total	3	6
4. Shale, blue	2	0
Concealed	5	0
3. Limestone, bluish, crystalline, thin bedded	5	0
Concealed	10	0
2. Limestone, fine grained, thin bedded	7	0
Concealed	13	0
1. Limestone, heavy bedded, buff to blue, probably magnesian	6	0

The shale beds, exclusive of the limestone bands, comprising No. 5 of the section at Potosi Station, No. 2, at Waupeton, and Nos. 4 and 5, at McCartney, were analyzed with results given below:

Analyses of shale from upper division of Platteville formation.

[Analyst, L. G. Michael, Ames, Iowa.]

	Potosi.	Waupeton.	McCartney.
Silica (SiO_2)	48.88	50.69	49.10
Alumina (Al_2O_3)	14.54	15.63	17.15
Ferric oxide (Fe_2O_3)	12.00	4.83	8.46
Calcium carbonate ($CaCO_3$)	8.58	11.15	11.04
Magnesium carbonate ($MgCO_3$)	3.15	8.43	2.85
Sulphur trioxide (SO_3)	1.26	2.65	1.69
Alkalies, as K_2O	6.43	1.46	3.62
Combined water	4.48	4.64	5.36
Moisture	1.30	.49	.91

For cement manufacture all these shales should preferably carry higher percentages of silica and less iron oxide in order that the ratio

$Al_2O_3 + Fe_2O_3 = \frac{SiO_2}{3}$ should be more nearly approximated. The alumina and iron oxide together should not be greater than $\frac{SiO_2}{2}$ and it is apparent from the above analyses that at Potosi Station, as well as at Spechts Ferry, their sum is greater than this. It is desirable, therefore, both on account of the chemical composition and the relative thinness of the shale beds, that some other supply of silica and alumina should be at hand. It is possible that such a supply might be obtained from the residual clay and loess at the top of the hills wherever these materials average rich in silica and poor in lime. An idea of the composition of the clay and loess present in the region can be had from the accompanying analyses. While the samples of clay and loess were not taken from the same sections as the limestone and shale, there is an abundance of this unconsolidated material above the Galena beds at each locality, and its composition is probably such that it may be considered an important factor in the situation.

Analyses of residual clay and loess from the Driftless Area. [a]

[Analyst, R. B. Riggs.]

	1.	2.	3.	4.	5.	6.
SiO_2	71.13	49.59	53.09	49.13	72.68	64.61
Al_2O_3	12.50	18.64	21.43	20.08	12.03	10.64
Fe_2O_3	5.52	17.19	8.53	11.04	3.53	2.61
FeO	.45	.27	.86	.93	.96	.51
TiO_2	.45	.28	.16	.13	.72	.40
P_2O_5	.02	.03	.03	.04	.23	.06
MnO	.04	.01	.03	.06	.06	.05
CaO	.85	.93	.95	1.22	1.59	5.41
MgO	.38	.73	1.43	1.92	1.11	3.69
Na_2O	2.19	.80	1.45	1.33	1.68	1.35
K_2O	1.61	.93	.83	1.60	2.13	2.06
H_2O (+H of organic matter	4.63	10.46	10.79	11.72	2.50	2.05
CO_2	.43	.30	.29	.39	.39	6.31
C	.19	.34	.22	1.09	.09	.13
SO_3					.51	.11

[a] Sixth Ann. Rept. U. S. Geol. Survey, 1885, pp. 250, 282.

Nos. 1 and 2 are samples of clay from the same vertical section, No. 1 having been taken 4½ feet from the surface and No. 2 a little more than 8½ feet from the surface, in contact with the underlying limestone. Nos. 3 and 4 are samples of clay that are similarly related, having been taken, respectively, 3 and 4½ feet from the surface, the latter clay in contact with the rock. No. 5 is loess from Dubuque, Iowa; No. 6 is loess from Galena, Ill.

A review of the character of the materials available shows that a cement manufactured in this district would be of the type made from a mixture of ordinary hard limestone and clay or shale. About 36 per cent of the Portland cement now made in the United States is of this type. Magnesium carbonate, the most objectionable of impurities in raw limestone materials, falls in these rocks well within the

maximum allowable limits of 5 to 6 per cent. Certain of the limestone beds that are high in silica resemble very closely in composition the "cement rock" of the well-known Lehigh Portland cement district.

The materials in this district would require very little preliminary drying. The limestone is fairly uniform in texture, but it would need very thorough grinding. The shale, clay, and loess are less refractory, and although the clay and loess carry a few chert or quartz pebbles such objectionable material is not excessive and could be removed by screening.

The Dubuque district is, of course, not ideally situated with regard to a fuel supply, but its distance from the Iowa coal field is not so great as the distance of certain successfully operated cement plants from their fuel base. A possible substitute, at least in part, for coal might be furnished by the great quantities of sawdust and slabs wasted by the several sash and door factories and other lumber mills at Dubuque. This fuel might be utilized in the kilns in the form of producer gas.

PORTLAND CEMENT MATERIALS IN EASTERN WYOMING.

By Sydney H. Ball.

INTRODUCTION.

In 1906 the writer examined shale and limestone beds in the vicinity of Newcastle and Cheyenne, Wyo., in order to ascertain the possibility of establishing a Portland cement plant in eastern Wyoming. At present there is no Portland cement plant in Wyoming (see fig. 8), the cement used in the State being shipped either from the Middle West or from Colorado, Utah, or South Dakota. The demand for Portland cement in the Western States is growing enormously. The Government is using large amounts of cement on its reclamation projects in Wyoming and adjoining States, and the mines in Montana and in the Black Hills of South Dakota use large quantities in installing their plants. Further, the railroads must soon use cement or masonry for culverts and bridges or cease to use as fuel western coal of poorer grades, which being light blows out of the smokestacks and starts fires that burn wooden bridges. The consumption of Portland cement in the towns in Wyoming is increasing at a rapid rate and with the introduction of cheaper cement the demand would increase. The conditions would seem to justify the establishment of a Portland cement plant within the State.

In connection with the preparation of this paper, Mr. E. C. Eckel, of the United States Geological Survey, has given the writer the benefit of his experience, and Prof. J. A. Holmes has furnished analyses made in the structural materials laboratory of the United States Geological Survey at St. Louis, Mo., the analysts being A. J. Phillips and P. H. Bates.

NEWCASTLE.

SITUATION.

Newcastle is situated in Weston County, Wyo., near the South Dakota line, on the southwestern slope of the Black Hills. It is on the main line of the Burlington and Missouri Valley Railroad, a spur of which runs from the town to large coal mines at Cambria. The country naturally tributary to a Portland cement plant at Newcastle

includes northwestern Wyoming, the Black Hills in South Dakota, northwestern Nebraska, and all of Montana. (See fig. 8, p. 240.)

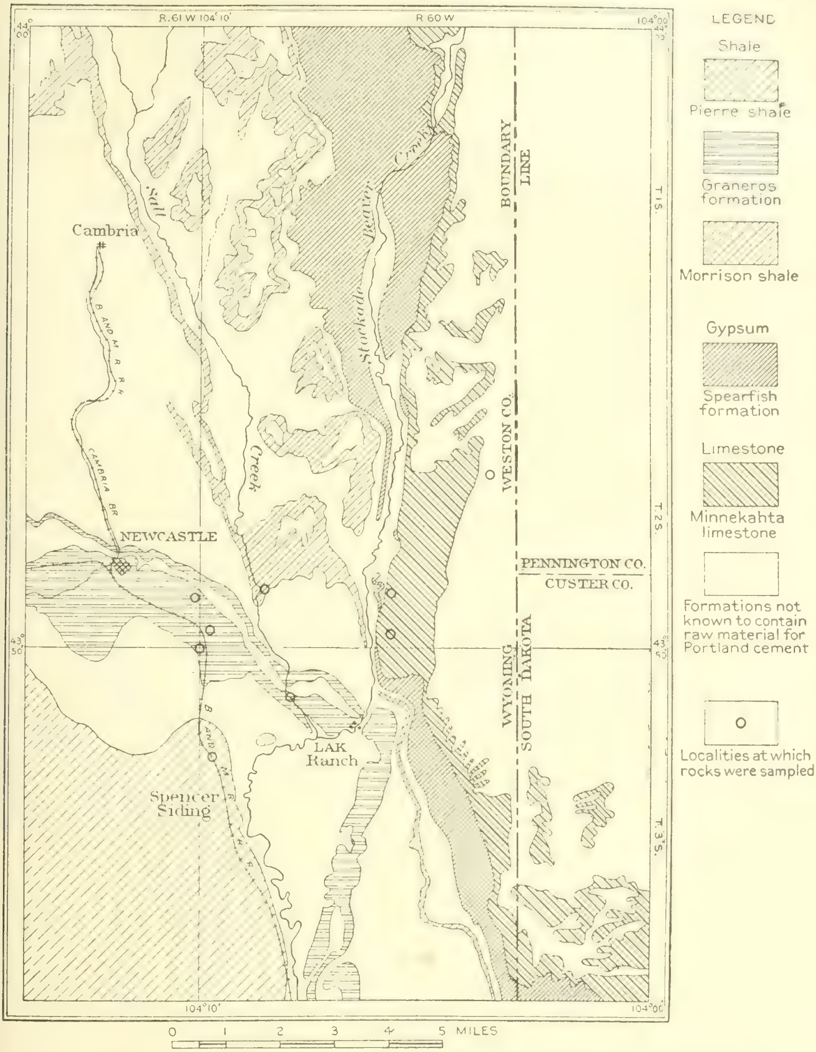

FIG. 7.—Map showing distribution of Portland cement raw materials in vicinity of Newcastle, Wyo. Generalized from geologic map in Newcastle folio, by N. H. Darton.

TOPOGRAPHY AND GEOLOGY.

North and east of Newcastle, toward the Black Hills, lies a highly dissected plain that rises toward the north, the geology of which has been described by N. H. Darton in the Newcastle folio.[a] Within

[a] Geologic Atlas U. S., folio 107, U. S. Geol. Survey.

the Newcastle quadrangle there are a large number of sedimentary formations, which range in age from Mississippian (Carboniferous) to Recent. These formations (see fig. 7) are distributed in bands which to the north and east of Newcastle have a north-south trend, and in the immediate vicinity of the town and in an area northwest of it occur in layers that course from northwest to southeast. As one travels west and southwest, away from the Black Hills central core of older rocks, he passes successively over younger and younger formations. The older ormations therefore lie northeast and east of Newcastle.

RAW MATERIALS.

The raw materials used in the manufacture of Portland cement are limestone (which typically contains but little magnesium carbonate) and shale or clay. In the vicinity of Newcastle the Minnekahta limestone, the Morrison shale, the Graneros shale, and the Pierre shale furnish suitable raw materials.

NATURAL CEMENT ROCK.

A calcareous shale, rather fissile and of light-gray color, a part of the Graneros shale, is exposed on the north side of the small stream that is crossed by the railroad 2¼ miles southeast of Newcastle. A thickness of 40 feet of shale is exposed on a small whitish hill west of the railroad. The amount of gypsum in this shale is too small to interfere with its use as a Portland cement material. Interbedded with the shale, 20 feet from the top of the sampled portion, are thin beds of limestone one-half inch thick. The shale occurs here in considerable bodies, which could probably be worked with a steam shovel. The following is an analysis of this limy shale, or shaly limestone, as it appears to be, made by Messrs. Phillips and Bates:

Analysis of shale from point 2¼ miles southeast of Newcastle.

Silica (SiO_2)		18.10
Alumina (Al_2O_3)		6.26
Ferric oxide (Fe_2O_3)		.80
Manganese oxide (MnO)		.50
Lime (CaO)		37.57
Magnesia (MgO)		.76
Sulphuric anhydride (SO_3)		.27
Alkalies	Na_2O	2.14
	K_2O	.92
Water at 100° C		1.25
Ignition loss		31.58
		100.15

This highly clayey limestone would make an excellent base for the manufacture of cement, and if mixed with a small amount of pure

limestone (about 10 per cent) would make Portland cement of high grade.

LIMESTONE.

Minnekahta limestone.—The Minnekahta limestone is exposed on the east side of Stockade Beaver Creek, where it forms the slopes and top of the lower of two benches. Here it is a rather thin-bedded limestone of light-gray or purplish color, averaging less than 40 feet in thickness. It includes at some places a few nodules of flint, but these can be easily separated from the pure limestone in the manufacture of Portland cement, and where the rock was sampled they seem to be absent. The localities at which samples were taken are respectively 1½ and 2¾ miles north and a little east of the L A K ranch, on the east side of Stockade Beaver Creek and the road. Analysis 1, below, is by Mr. P. H. Bates; analysis 2 is by Mr. A. J. Phillips.

Analyses of Minnekahta limestone.

Constituent.	1.	2.
Silica (SiO_2)	1.08	1.42
Alumina (Al_2O_3)	.33	.68
Ferric oxide (Fe_2O_3)	.77	.40
Manganese oxide (MnO)	.46	.11
Lime (CaO)	53.40	52.85
Magnesia (MgO)	.57	.72
Sulphuric anhydride (SO_3)	.12	.12
Alkalies { Na_2O	.36	.76
Alkalies { K_2O	.16	.30
Water at 100° C	.20	.10
Ignition loss	42.92	42.78
	100.37	100.24

This is a pure limestone and an excellent constituent of a Portland cement mixture, containing low magnesium carbonate and sulphur. The supply of limestone here is practically inexhaustible, and since the bed dips gently to the west, the rock could be readily quarried and shot down to or nearly to the railroad by gravity. A branch railroad could be built from the main line to either point cheaply.

Pahasapa limestone.—The Pahasapa limestone is exposed in a thin band about 1½ miles west of Stockade Beaver Creek. An analysis of the rock by Mr. P. H. Bates is as follows:

Analysis of Pahasapa limestone.

Silica (SiO_2)	4.02
Alumina (Al_2O_3)	.10
Ferric oxide (Fe_2O_3)	.94
Manganese oxide (MnO)	.22
Lime (CaO)	36.68
Magnesia (MgO)	14.14

Sulphuric anhydride (SO_3)	0.05
Alkalies { Na_2O	.33
Alkalies { K_2O	.09
Water at 100° C	.25
Ignition loss	43.65
	100.47

This rock contains too much magnesia to be used for the manufacture of Portland cement.

SHALE.

Morrison shale.—The most important exposures of Morrison shale, which is the lowest Cretaceous formation here and is 150 feet thick, cover considerable portions of the drainage basin of Salt Creek. The shale at the supposed coal prospect on the east bank of Salt Creek 3 miles above its mouth is carbonaceous and slightly plastic. It contains a little iron pyrite in nodules and few if any sand grains. An average sample from the 20-foot face exposed here was analyzed by Mr. P. H. Bates.

Analysis of Morrison shale.

Silica (SiO_2)	45.78
Alumina (Al_2O_3)	12.92
Ferric oxide (Fe_2O_3)	3.96
Manganese oxide (MnO)	.33
Lime (CaO)	.56
Magnesia (MgO)	.73
Sulphuric anhydride (SO_3)	.42
Alkalies { Na_2O	.64
Alkalies { K_2O	.50
Water at 100° C	8.26
Ignition loss	26.32
	100.42

This is a high-grade normal shale, in which the ratio of silica to combined alumina and ferric iron is practically 3 to 1—an ideal ratio. The magnesia and alkalies are very low, and although silica is low the loss by ignition (largely carbonaceous matter) is very high. This carbonaceous matter can be considered as so much fuel added to the mixture, and its presence will considerably decrease the cost of burning.

Graneros shale.—The Graneros shale underlies the broad valley south of Newcastle, comprising an area extending from the L A K ranch northwestward to and for several miles along the Burlington and Missouri River Railroad. From the ranch the outcrop of the formation swings approximately southward, and because of steeper dips becomes narrower. It consists mainly of dark-gray shale, and in the vicinity of Newcastle is about 1,100 feet thick. Thin veinlets of gypsum are common in the shale, but at no point are these so abundant as to make it unfit for use as Portland cement material.

Of three samples analyzed, one (analysis 1 below) was collected immediately south of the point where the road from Newcastle to the L A K ranch crosses Salt Creek. The shale here is dark gray and fissile. No gypsum was seen at this point, although some fragments of shale are covered with a yellowish coating which has an astringent taste, probably due to the presence of ferrous sulphate. The second sample (analysis 2) was collected at a point 2¼ miles southeast of Newcastle, between the wagon road and the railroad. Here the shale is black and fissile and dips gently to the southwest. The hill from which the sample was taken is 40 feet high, and the surrounding valley is underlain by shale, presumably of similar composition. The shale contains numerous crystals of gypsum, and gypsum occurs also in thin plates along the joint faces. It is soft and could doubtless be worked by a steam shovel with but little blasting. The third sample was collected from a hill 1½ miles south of east of Newcastle, near a prominent ridge formed by the sandstone lens in the Graneros shale. At this place there is a large body of gray shale without sand grains or gypsum, but its analysis is much less satisfactory than those of the two previous samples. Analysis 1, below, is by A. J. Phillips and P. H. Bates; analyses 2 and 3 are by P. H. Bates.

Analyses of samples of Graneros shale.

Constituent.	1.	2.	3.
Silica (SiO_2)	67.55	58.82	68.30
Alumina (Al_2O_3)	17.58	16.43	14.65
Ferric oxide (Fe_2O_3)	.47	4.47	.37
Manganese oxide (MnO)	.18	.24	.33
Lime (CaO)	.36	.54	1.18
Magnesia (MgO)	.74	1.68	1.03
Sulphuric anhydride (SO_3)	.50	1.32	.09
Alkalies Na_2O	.21	.33	.30
Alkalies K_2O	.79	2.18	.39
Water at 100° C.		6.39	6.82
Ignition loss	11.68	7.93	6.56
	100.26	100.33	100.02

Analyses 1 and 2 show a normal shale with a high content of silica and a ratio of silica to iron and alumina that would make the rock a satisfactory cement-making material. Analysis 1, however, shows a percentage of ferric oxide so small that the cement mixture would be infusible, but analysis 2 is in every way that of a shale well fitted for making Portland cement. Analysis 3 shows that the rock analyzed contains entirely too much silica and too little ferric iron to be of value.

Pierre shale.—Pierre shale covers a large area lying south and southwest of Newcastle, the nearest exposures being situated 3 miles from town. The Pierre is a dark-gray shale, about 1,250 feet thick. It is

characterized in places by limestone concretions, some of which are very large. A sample was taken along the railroad track 1 mile above Spencer siding, where the shale is greenish gray in color, fine grained, and without gypsum. It is soft and could be readily mined by steam shovel. The following analysis is by Phillips and Bates:

Analysis of Pierre shale.

Silica (SiO_2)		60.66
Alumina (Al_2O_3)		22.13
Ferric oxide (Fe_2O_3)		1.21
Manganese oxide (MnO)		.44
Lime (CaO)		1.59
Magnesia (MgO)		1.54
Sulphuric anhydride (SO_3)		.43
Alkalies	Na_2O	.53
	K_2O	2.16
Ignition loss		9.28
		99.97

The shale has high silica and rather low magnesia and alkalies. Its silica content is 2.6 times that of the alumina and ferric iron, the iron content being so small that the rock would form with limestone an infusible mixture.

GYPSUM.

Two or three per cent of gypsum is usually added to the clinker of Portland cement to retard setting. Gypsum occurs in considerable amount in the "Red Beds" (Spearfish formation) exposed along Stockade Beaver Creek.

ECONOMIC CONDITIONS.

Some of the rocks just described are excellent raw material for Portland cement; and the supply at the points where the samples were taken is adequate to run a Portland cement plant for a long time. Further, if the present outcrop of any of these limestones or shales were exhausted, the same rock could be found beneath a thin covering of soil over large areas in the immediate vicinity. The average sample collected represents thicknesses of 20 to 150 feet. The analyses represent not alone the shale or limestone at the point where samples were taken, but give a fair idea of the shale or limestone along the same strike for a long distance.

The best combination for a Portland cement mixture is about 90 per cent of the natural cement rock and 10 per cent of the Minnekahta limestone. The highly clayey limestone or natural cement rock occurs along the railroad, and the limestone could be obtained by running a spur to a point on Stockade Beaver Creek 1 mile above the L A K ranch. This branch road, which would not be more than

5 miles long, would have a gentle grade. Coal could be shipped from Cambria at a maximum cost of $1 per ton f. o. b. at the plant. This coal[a] furnishes a fair amount of heat, and although high in sulphur and ash, the former would largely disappear in the burning and the latter would be incorporated with the cement. The Portland cement plant should be situated on the railroad at the outcrop of the natural cement rock. A well sunk here for the water necessary to run the plant would probably strike flowing water at a depth of 1,000 to 1,500 feet from the surface.

If limestone and shale are to be used, the best combination appears to be the Graneros or the Morrison shale and the Minnekahta limestone. The most desirable Graneros shale is that sampled from the hill approximately 2¼ miles southeast of Newcastle, between the railroad and the wagon road, and the plant should be situated on the railroad at this point. A branch railroad, approximately 5 miles long, following the depression marked by the exposure of the Graneros shale and swinging slightly to the north of the L A K ranch and thence to Stockade Beaver Creek, would reach ledges of Minnekahta limestone. The use of the Morrison shale would require a railroad with two spurs, one up Stockade Beaver Creek for limestone and the other up Salt Creek for shale. In this instance the mill would most advantageously be situated at the fork of the spurs. It is possible, however, that suitable exposures of shale could be found on or immediately west of Stockade Beaver Creek, in which case both limestone and shale would be close to a plant situated on Stockade Beaver Creek and using its water. The mill would then be located 4 or 5 miles above the L A K ranch.

RÉSUMÉ.

The region tributary to Newcastle is rather large, and although the town has but one main railroad the cement could no doubt be easily marketed. The raw materials are high in grade and abundant in quantity, and cheap fuel of fair quality is at hand. With good management a Portland cement plant situated at Newcastle could unquestionably be run at a profit.

VICINITY OF CHEYENNE.

Cheyenne, the capital of Wyoming, is in Laramie County, in the southeast corner of the State. It lies on the main lines of the Union Pacific and Chicago, Burlington and Quincy railroads, and from it the Colorado and Southern Railroad runs northward to connect with the Chicago and Northwestern Railroad, and the Union Pacific runs

[a] Report on operations of coal-testing plant of the United Statse Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904: Prof. Paper U. S. Geol. Survey No. 48, pp. 263, 946, 953, 1313.

southward to Denver. The map (fig. 8) shows that the area to which a Portland cement plant in this portion of Wyoming would ship its product includes eastern Wyoming, western Nebraska, northeastern Colorado, and a part of northwestern Kansas.

TOPOGRAPHY AND GEOLOGY.

Solid rocks are not exposed in the immediate vicinity of Cheyenne, but along the east edge of the Laramie Front Range there is practically the same succession of Paleozoic and Mesozoic rocks that occurs in the Black Hills. These old rocks are crossed by the Colorado and Southern Railroad at two points, and were examined by the writer at Iron Mountain station, about 40 miles from Cheyenne. At Iron Mountain the rocks are tilted steeply to the east and the mountain front is in

FIG. 8. Map showing location of Cheyenne and Newcastle, Wyo., in relation to established Portland cement plants and transcontinental railroads.

consequence marked by rugged hogbacks and valleys, formed respectively on resistant sandstone beds and soft shales. The strata in general strike north-south and dip eastward at an angle of about 70.°

RAW MATERIALS.

The formations sampled in the vicinity of Iron Mountain include limestones from the Niobrara formation and the Minnekahta limestone, and shales from the Graneros formation and the Pierre shale.

LIMESTONE.

Niobrara formation.—The best limestone sampled is from a hill of Niobrara which lies east of the end of the Bradley spur, across a narrow flat. It is a thin-bedded shaly white limestone and is here and there fossiliferous. The rock shows at many places small yellowish-

brown iron stains $1\frac{1}{2}$ inches in diameter. The limestone is practically on edge and could be cheaply quarried, possibly by the use of steam shovels, although considerable blasting would probably be necessary with increase in the depth of the quarry. About 60 feet of this limestone is exposed, but it is probable that a greater thickness could be proved by test pits in the flat to the west. The rock was traced for a distance of one-eighth of a mile on this same hill, and again outcrops across a small brook to the south. The highest point of the exposure is about 100 feet above the valley and unquestionably there is sufficient limestone here to last a large plant many years. The following analysis by Mr. A. J. Phillips is that of a sample taken across 60 feet of the limestone.

Analysis of Niobrara limestone.

Silica (SiO_2)	6.44
Alumina (Al_2O_3)	1.46
Ferric oxide (Fe_2O_3)	2.32
Manganese oxide (MnO)	.11
Lime (CaO)	45.90
Magnesia (MgO)	2.65
Sulphuric anhydride (SO_3)	.07
Alkalies (K_2O)	.66
Water at 100° C	.55
Water above 100° C	.33
Ignition loss	39.71
	100.10

This is a good limestone for cement making, although the percentage of silica as compared with that of the combined alumina and ferric oxide is low. Magnesian carbonate is not particularly high, while sulphur, the alkalies, and silica are exceedingly low.

Minnekahta limestone.—A little over one-half mile west of Bradley station the Minnekahta limestone (Carboniferous) forms a prominent escarpment and bench extending parallel to the front of the range. It can be readily recognized from its topographic form, and from the fact that it is underlain and overlain by red beds. The limestone is 50 feet thick. In the escarpment it dips S. 80° E. at an angle of 65°, and to the west, on the bench or terrace, it becomes approximately flat. It is gray, purplish, or white in color, and is mostly fine grained, dense, and rather hard. Joints are common throughout the mass and these would be of considerable advantage in quarrying. Its situation for quarrying, however, is unfortunate, since either the overlying red shales, which mask the lower portion of the cliff, would have to be shot off before the limestone could be quarried, or the quarry would have to be located upon the top of the bench and an expensive tramway built to the flat below. A railroad to the base of the cliff would probably have a rather steep grade. A

sample taken across 50 feet of this formation was analyzed by A. J. Phillips with the following result:

Analysis of Minnekahta limestone.

Silica (SiO_2)		10.52
Alumina (Al_2O_3)		.46
Ferric oxide (Fe_2O_3)		1.55
Manganese oxide (MnO)		.14
Lime (CaO)		43.30
Magnesia (MgO)		3.53
Sulphuric anhydride (SO_3)		.06
Alkalies	(Na_2O)	.05
	(K_2O)	.70
Water at 100° C		.50
Ignition loss		39.22
		100.03

This limestone, having a high silica content and a comparatively low sum of alumina and ferric oxide, is much poorer in quality than the Niobrara; otherwise it is fairly good, containing low sulphur and not prohibitively high magnesia. Better analyses of particular beds of the Minnekahta limestone have been obtained by private parties.

SHALE.

Graneros shale.—At the end of the railroad spur at Bradley station 140 feet of shale is exposed in a trough lying between the Dakota sandstone hogback on the west and the hogback formed by the sandstone lens in the Graneros formation on the east. The upper 25 feet of the shale, which here dips N. 85° E. at an angle of 80°, is sandy and is unfit for making Portland cement. The lower 115 feet, however, is a dark-gray shale, slightly plastic, with little or no grit. A few ironstone nodules occur in the shale, but these have been included in the sample and are evidently not detrimental. The shale outcrops for three-eighths of a mile south and at least 1½ miles north of Bradley spur. It is soft and could be readily quarried by steam shovel. An analysis by Mr. A. J. Phillips of a sample taken across the middle 40 feet of the shale follows:

Analysis of Graneros shale.

Silica (SiO_2)		63.60
Alumina (Al_2O_3)		14.66
Ferric oxide (Fe_2O_3)		7.44
Manganese oxide (MnO)		.20
Lime (CaO)		.78
Magnesia (MgO)		.46
Sulphuric anhydride (SO_3)		.53
Alkalies	(Na_2O)	.37
	(K_2O)	1.79
Water at 100° C		2.86
Ignition loss		7.64
		100.33

This is a normal shale with high silica and an ideal ratio between alumina and ferric oxide and silica. The magnesia and the alkalies are rather low, while there is sufficient iron present to insure a fusible cement matrix.

Pierre shale.—The Pierre shale was sampled on the west side of the railroad track three-fourths of a mile N. 20° W. of Bradley station. The railroad is one-fourth of a mile due east of the shale deposit, and test pits would doubtless expose similar shale under the terrace gravels on the railroad east of the locality sampled. The shale is dark gray in color and is soft and fissile, many of the beds being paper thin; ellipsoidal masses in it are stained by iron, and it contains a very little selenite (transparent platy gypsum). Without much question it could be worked with a steam shovel. The following analysis, made by Mr. A. J. Phillips, is that of a sample taken across 100 feet of the rock:

Analysis of Pierre shale.

Silica (SiO_2)		62.34
Alumina (Al_2O_3)		21.98
Ferric oxide (Fe_2O_3)		7.92
Manganese oxide (MnO)		.26
Lime (CaO)		1.28
Magnesia (MgO)		.73
Sulphuric anhydride (SO_3)		.36
Alkalies	(Na_2O)	.19
	(K_2O)	1.71
Water at 100° C		1.83
Ignition loss		1.77
		100.27

This is a normal shale, scarcely as good as the shale last described and yet of fair quality. It has high silica and its combined aluminum and ferric oxide have the ratio to silica of 1 to 2.2. The percentage of sulphuric anhydride is too low to be detrimental.

GYPSUM.

Gypsum, suitable for use as a set retarder of Portland cement, is reported to occur in the "Red Beds" south of Iron Mountain.

ECONOMIC CONDITIONS.

A Portland cement plant at Iron Mountain should use for its raw materials the Graneros shale at the end of the Bradley spur and the Niobrara shaly limestone east of the same point. An extension of the Bradley spur one-quarter of a mile long would connect the two deposits. Chugwater Creek furnishes sufficient water for a mill on the railroad on its banks. Coal at Cheyenne is $4 to $5 a ton. To this price would necessarily be added the freight from Cheyenne to Iron Mountain on the Colorado and Southern Railroad. The fuel cost alone

would approximate 40 cents a barrel, which is over one-half of the total cost of manufacturing a barrel of Portland cement in the East. It is possible, however, that coal coming over the Colorado and Southern Railroad from the north would be cheaper.

COST OF A PORTLAND CEMENT PLANT.

It is perhaps worth while to add some general estimates of the cost of installing a Portland cement plant. The cost varies with the number of kilns constructed, although the proportional increase in cost is less with increase in the number of kilns. An 8-kiln plant, manufacturing 1,200 barrels of Portland cement in twenty-four hours, would cost from $360,000 to $400,000, while a 6-kiln plant would cost from $300,000 to $360,000.[a] Besides this first cost a large reserve capital is needed, since (1) each new plant during a period of experimentation makes cement that is below the grade required by contractors; (2) contractors are accustomed to use certain brands of Portland cement, and a new brand must establish a reputation before it can make large sales; (3) a Portland cement plant sells much of its product on long payments, but many of its own bills must be met at once. Mr. E. C. Eckel[b] further gives the following as an average cost per barrel at an 8-kiln plant, with 80-foot kilns, producing 2,000 barrels of Portland cement a day:

Cost of Portland cement per barrel.

Cement materials	$0.08
Power coal[c]	.08
Drier coal[c]	.01
Kiln coal[c]	.10
Labor	.10
Supplies, etc	.11
Office and laboratory	.03
Administration and sales	.05
Interest, etc	.12
	.68

In Wyoming the item of labor would be at least twice that here given, while at places near coal fields the item of fuel would be less by one-half, and for points distant from coal fields should be multiplied by two. It is therefore evident that Portland cement can be made in eastern Wyoming at a cost below the present local prices of eastern brands.

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[a] Eckel, E. C., Cements, limes, and plasters, N. Y., 1905, p. 556.

[b] Ibid., p. 561.

[c] At $2 a ton.

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LIME, MAGNESITE, ETC.

LIMESTONE AND DOLOMITE IN THE BIRMINGHAM DISTRICT, ALABAMA.

By Charles Butts.

INTRODUCTION.

Both limestone and dolomite are important from an economic standpoint in the Birmingham district. Limestone is used for lime and cement, and both limestone and dolomite are extensively utilized as flux in iron smelting. Indeed, this fluxing material is one of the three essential factors in the great industrial development of the Birmingham district, coal and iron, of course, being the other two. Along Birmingham Valley, from Bessemer to Trussville, ore, coal, and flux are to be had within a distance of 5 to 10 miles from each other, and it is due to the proximity of these three indispensable materials that profitable iron making from the comparatively low-grade ores of this region is possible. This paper is based on work done in the field by Chester W. Washburne, William F. Prouty, E. F. Burchard, E. M. Dawson, jr., and the writer. Other published reports have been freely drawn on for information, for which due acknowledgment is made in the proper place.

In this area there are three distinct limestone formations and one dolomite formation. These are the Bangor limestone, the Chickamauga ("Trenton") limestone, the Knox dolomite, and the Conasauga limestone, the highest being named first.

BANGOR LIMESTONE.

The Bangor limestone is of Carboniferous age and is named from Bangor, Ala., where it has been quarried. It is generally a semicrystalline, rather light-gray limestone, varying from a few feet to 300 feet or more in thickness.

This limestone outcrops along both sides of Blount Valley, from Reid station to Bangor and farther north, where it forms a considerable part of the valley walls, extending up nearly to the bottom of

the sandstone that caps the sand ridges or mountains overlooking the valley. It dips into the hills at angles of 5° to 15°.

The limestone is thus favorably situated for quarrying, and it has been worked on a considerable scale at Blount Springs and Bangor. One quarry between these two places, belonging to W. F. Harrell, is now in operation. This quarry is an open working and the face is almost 80 feet high, extending nearly to the top of the outcrop on the escarpment. The following is a section of the rock quarried:

Section of Bangor limestone at Harrell quarry.

	Feet.
Gray semicrystalline limestone	28
Dark semicrystalline limestone	12
Gray semicrystalline limestone	40

The limestone beds are separated by thin partings of carbonaceous shale. Limestone from this quarry is used for flux in the furnaces at Birmingham and Bessemer.

Other quarries have been operated along the outcrop, both at Bangor and Blount Springs. The one at Blount Springs was operated by the Sloss-Sheffield Steel Company. The composition of the limestone from this quarry, which includes a thickness of 100 feet or more, is as follows:

Average of eight analyses of Bangor limestone from Blount Springs quarry. [a]

Silica (SiO_2)	1.05
Iron oxide and alumina ($Fe_2O_3+Al_2O_3$)	.82
Lime carbonate ($CaCO_3$)	96.74
Magnesium carbonate ($MgCO_3$)	.71
	99.32

The Bangor limestone outcrops along the west side of Murphree Valley, and around the southern point of Blount Mountain, whence its outcrop extends along the valley of Canoe Creek to the neighborhood of Springville and beyond. At Dale is the quarry of the Republic Iron and Steel Company, of which the following is an approximate section:

Section of Bangor limestone at Dale quarry.

	Feet.
Limestone	20
Red shale	5
Green shale	5
Gray crystalline limestone	25
Dark limestone	30
White limestone	5
Shale	1
Clay	2
Gray limestone	60
	153

[a] Analyzed by Henry McCalley, J. L. Beeson, and J. R. Harris. Eckel, E. C., Cement materials and industry of the United States: Bull. U. S. Geol. Survey No. 243, 1905, p. 68.

In this quarry nearly the full face of the outcrop on the valley wall is quarried, the stone being used for flux. The beds dip into the hill at an angle of 15°. The limestone has been extensively quarried along this outcrop for some distance north of Dale, though all the workings except that at Dale have been abandoned. These abandoned workings suggest that the quarrymen continued operations to a point where it became necessary to remove too much cover and then moved to a new location. Below are analyses of the limestone in this locality:

Analyses of Bangor limestone from Compton quarry, north of Dale.[a]

	1.	2.	3.
Silica (SiO_2)	2.05	4.45	2.80
Iron oxide and alumina ($Fe_2O_3 + Al_2O_3$)	.76	3.30	.70
Lime carbonate ($CaCO_3$)	89.64	86.35	94.59
Magnesium carbonate ($MgCO_3$)	8.15		

[a] Eckel, E. C., loc. cit.

1. Average sample of 150 feet of rock used as flux. J. L. Beeson, analyst.
2 and 3. Stockhouse samples. W. B. Phillips, analyst.

These analyses show considerably more silica and magnesia in the limestone in this locality than at Blount Springs. Analysis No. 2, however, is the only one that shows an injurious amount of silica with a corresponding low percentage of lime carbonate.

The limestone outcropping around the south end of Blount Mountain and on Canoe Creek has never been utilized. The formation is exposed high up on the west face of the mountain east of Village Springs, where it must reach a thickness of 300 feet. The outcrop along the west side of Birmingham Valley has been traced southward to Sayreton Gap, near North Birmingham. The limestone thins toward the south, being at Boyles Gap 50 to 100 feet thick and at Sayreton Gap only a few feet. South of Sayreton Gap it has not been identified. In Shades Valley but little can be discovered of this limestone. The top of the formation outcrops just south of Trussville, where it has been quarried. Between Trussville and Argo is another small showing. Limestone is reported in wells at Trussville at a depth of 12 feet. Along Shades Valley south of Irondale only chert and shale were observed in outcrop, and although thin beds and lenses of limestone are known to occur in the generally sandy material of this part of the valley, the deposits can have no economic importance. A considerable thickness of chert shows along the valley south of Trussville, and it is probable that the Bangor limestone has been more or less replaced by shale and other siliceous matter along this belt, a change that becomes complete farther to the southeast in the Cahaba Valley, east of Leeds, where the limestone is practically absent, having been entirely replaced by shale.

CHICKAMAUGA ("TRENTON") LIMESTONE.

The Chickamauga limestone is of Ordovician or lower Silurian age. Its stratigraphic position is below the Rockwood (Clinton) formation, which carries the red ores of the region, and above the Knox chert. In Birmingham Valley this limestone outcrops along the west escarpment of Red Mountain almost the entire distance from a point south of Bessemer nearly to Springville and thence southward along the east side of Red Mountain nearly to Trussville. There are several gaps in this outcrop that are probably due to faults, but perhaps in some places to nondeposition of the limestone. One of these is on the west side of Red Mountain, 1 mile south of Saddlers Gap; another extends northward from Clay for 2 miles, and another about 3 miles in length is northeast of Ayres. The limestone appears to be absent along the west side of the Cahaba trough from a point 1 mile south of Argo northeastward to the boundary of the Birmingham quadrangle. It outcrops along the west side of Birmingham Valley and makes the east face of West Red Mountain from the vicinity of Cunningham Gap to Dale and thence, along the same belt, extends up Murphree Valley to Chepultepec and beyond. South of Cunningham Gap the outcrop thins gradually and finally disappears about 2 miles to the south, being cut off diagonally by a fault. Along the east side of Murphree Valley it is cut out by a fault as far south as Village Springs. Around the south end of Blount Mountain it outcrops in a broad belt extending from Village Springs to Springville and thence northward parallel to the east side of Blount Mountain. A belt of Chickamauga limestone also extends down the east side of East Red Mountain from Canoe Creek nearly to Trussville.

Along all the outcrops described above the limestone is generally rather thin bedded and light or dark gray in color. In places, as at Dale and west of Swansea, there is a thick-bedded buff limestone near the base, and at the south end of Blount Mountain purple-mottled layers occur through the lower 25 feet or more. Crystalline limestone also occurs in the formation. The Chickamauga limestone appears to run from 300 to 700 feet in thickness except where affected by faults, as described above. Its thickness at Gate City is about 300 feet, on Blackburn Fork, west of Swansea, 500 feet, at Chepultepec 600 to 800 feet, and on Butler Mountain, at the south end of Blount Mountain, 700 to 800 feet. The limestone dips into the hills on either side of the valleys, generally at angles of 15° to 20°, though higher dips may occur locally. In some localities, as in the region of Butler and Foster mountains, it lies nearly flat.

The Chickamauga limestone outcrops along Cahaba Valley in a belt about 1 mile wide. In fact the valley has been eroded in the limestone, which is less resistant than the rocks on either side. Leeds is

situated near the center of this valley, the limestone showing on all sides. The limestone in Cahaba Valley is generally dark gray and it is much thicker bedded, especially in the lower part, than along Birmingham Valley. Its thickness is difficult to determine accurately on account of probable irregularities of dip, but it may be as much as 1,000 feet. Its dip in the vicinity of Leeds is 15° to 20° SE., and about 4 miles south of Leeds dips of 50° E. were noted.

The Chickamauga limestone has been quarried at Gate City by the Sloss Iron Company for use as flux, but it is no longer used in this region for that purpose to any extent. The subjoined analyses show the composition of the limestone at this quarry:

Analyses of Chickamauga limestone at Gate City quarry.[a]

	1.	2.
Silica (SiO_2)	5.70	3.30
Iron oxide (Fe_2O_3)	1.87	2.14
Lime carbonate ($CaCO_3$)	91.16	91.33

[a] Eckel, E. C., loc. cit.

1. Average sample from crusher. Henry McCalley, analyst.
2. Average of four samples. J. W. Miller, analyst.

The high percentage of silica shown by these analyses probably indicates the reason why the use of this limestone as flux has been discontinued. Much purer rock can be obtained in the region, as is shown on page 253.

This limestone is used for lime near Chepultepec, in Murphree Valley, by the Cheney Marble and White Lime Company. The quarry is situated on the east face of West Red Mountain, where the situation is favorable for working the rock. Below is a section of the limestone exposed in this quarry:

Section of Chickamauga limestone at Chepultepec quarry.

	Feet.
Dark-gray crystalline limestone	40
Darker crystalline limestone	20
Blue limestone	5
Gray limestone	2
Blue limestone	5
Shaly, impure limestone	6
Dark amorphous (lithographic?) limestone	2
Gray limestone	10
	90

The gray limestone at the top is the chief source of material for lime. At the time the works were visited (September, 1905) two kilns were in operation, each producing 100 barrels of lime daily.

At Leeds, in Cahaba Valley, a large plant has been built which will use the Chickamauga limestone, quarried near the works, for cement

manufacture. The limestone here is thick bedded and dips 15° to 20° E. As it outcrops but little above drainage level, quarrying operations will be more difficult and expensive than in a quarry entirely above drainage. So far as its known composition indicates, this limestone is everywhere suitable for cement manufacture.

The most favorable locality for quarrying the limestone in this region, with regard to natural conditions, is at the south end of Blount Mountain, where it lies nearly flat and forms high hills such as Foster and Butler mountains. From 500 to 700 feet of limestone is here available, entirely above drainage and exposed on all sides. This locality could be easily reached from the Louisville and Nashville Railroad by a spur 3 miles long, leaving the main track 2 miles north of Mount Pinson and extending up Dry Creek to Foster Mountain.

KNOX DOLOMITE.

The lower 500 to 600 feet of the Knox dolomite, which is free from the chert characterizing the upper 2,500 feet of the formation, is largely used as flux in the furnaces of the district. This chert-free dolomite is limited below by the thin-bedded, bluish to dark-gray Cambrian limestone known as the Conasauga limestone.

The dolomite outcrops along the east side of Opossum Valley, being quarried by the Tennessee Republic Company at Thomas and by the Sloss Iron Company at North Birmingham. The outcrop in Opossum Valley continues as a narrow belt up the west side of Birmingham Valley to Mount Pinson. Along the east side of Birmingham Valley the outcrop extends in a narrow belt to a point within 1 mile of Chalkville. Besides the quarries mentioned above, the Spencer quarry of the Lacy-Buck Iron Company at Lardona and that of the Tennessee Republic Company at Ketona, as well as the old quarry at Dolcito, are located along the western belt. The eastern and western belts of outcrop are connected between North Birmingham and East Birmingham, where the dolomite lies nearly flat and makes a wide outcrop separating the chert ridge in Birmingham, known as Cemetery Ridge, from the chert ridge extending northeastward from East Birmingham to Blount Mountain. There is an outcrop of the dolomite in Murphree Valley extending along the east side of Gravelly Ridge from Chepultepec to Remlap. It is well exposed on Blackburn Fork west of Swansea, as a bluff about 100 feet high. The dolomite is also known to occur along the east side of the Cahaba trough, at the west base of Pine Mountain, where, on account of its vertical attitude, its outcrop is narrow, though it probably extends for 10 miles diagonally across the southeast corner of the Birmingham quadrangle.

The dolomite is generally gray in color and more or less crystalline in texture. As shown by the accompanying analyses, it is nearly free from silica, though thin plates of chert or silica in some other form are

said to occur in the rock at various points. At the top it begins to show more or less abundant chert inclusions, such as nodules, stringers, and thin irregular sheets. This transition may be observed in the vicinity of the abandoned Dolcito quarry, where the overlying cherty phase of the Knox is fairly well exposed. The rock is in most places thick bedded. In weathering much of the surface becomes granular, simulating closely the appearance of a coarse-grained sandstone. As stated above, the thickness of this dolomite seems to be about 500 feet. It was measured in Opossum Valley, west of Birmingham, and along the section from the Spencer quarry through Lardona, where the top and bottom can be determined within reasonably close limits. There may be considerable variation from this thickness, however, in different parts of the region. The dip along the western belt, where the quarries mentioned above are located, is from 10° to 15° E.

From this dolomite is obtained all the flux quarried in the Birmingham quadrangle except that obtained from the Bangor limestone. At the quarries of the Tennessee Republic Company at Ketona, and of the Sloss Iron Company at North Birmingham, this rock is a nearly pure calcium and magnesian carbonate, as shown by the following analyses:

Analyses of dolomite from Ketona and North Birmingham quarries.

	1.	2.
Silica (SiO_2)	1.31	0.70
Alumina (Al_2O_3)	.96	.63
Lime carbonate ($CaCO_3$)	55.80	56.41
Magnesium carbonate ($MgCO_3$)	42.47	43.00

1. Average of four analyses of average sample from Ketona quarry, August to October, 1903. Analyses furnished by Tennessee Republic Company.
2. Average of ten analyses of carload lots from North Birmingham quarry, August, 1903, to June, 1905. Analyses furnished by Sloss Iron Company.

These analyses indicate that the lime and magnesia in this rock are nearly in the proportions of the mineral dolomite and that it is properly called dolomite. W. B. Phillips[a] has made a number of silica determinations from the dolomite in the vicinity of Dolcito. At the south end of the Dolcito quarry, which had a face of 17 feet at the time of sampling, samples taken from every foot of the face showed a range of 0.48 to 0.88 per cent of silica, with an average of 0.64 per cent. At the northeast end of the same quarry, presumably from the same beds as at the southwest end, though not so stated, the silica, in samples taken in the same way, ranged from 0.48 to 4.58 per cent, with an average of 1.69 per cent. This shows a considerable variation within a short distance. Two miles northeast of Dolcito, on Fivemile Creek, 29 samples taken at intervals from top to bottom of

[a] Geol. Survey Alabama, Rept. on Valley Regions, pt. 2, 1897, pp. 323-326.

116 feet of dolomite gave silica ranging from 0.96 to 7.28 per cent, with an average of 3.26 per cent. This shows a still greater increase in silica content to the northeast. The writer suspects that in the latter case the samples were obtained at a horizon above the true chert-free dolomite, which north of Dolcito is apparently confined to the flat land along the valley and does not show in outcrop to any extent.

On account of the fact that the dolomite outcrops along the valley bottoms but little above drainage the conditions for quarrying are not very favorable, inasmuch as it is necessary to keep the quarries dry by constant pumping and the rock has to be raised from considerable depth. It is especially difficult to keep the quarries dry in heavy and prolonged rains, and at times work has to be suspended on account of flooding.

The most favorable conditions for quarrying exist in Murphree Valley between Remlap and Chepultepec, where the dolomite outcrops well up on the east side of Gravelly Ridge, and though the rock dips to the west at a considerable angle large bodies could be quarried in such a way as to be self-draining; moreover, the expense involved in raising the rock from a deep quarry on level ground would be entirely avoided.

The suitability of this dolomite for flux has been amply demonstrated by its use in the furnaces of the region for the last ten years, and no comments on that phase of the matter need be made here. The results obtained in actual use throughout this period prove that the dolomite is in every respect equal to the best limestone to be had in the region for fluxing purposes. One company reports its exclusive use in smelting iron for the manufacture of steel by the basic process. The abundance of the rock in proximity to the furnaces is another condition favoring its use.

CONASAUGA LIMESTONE.

The Conasauga limestone is a thin-bedded bluish to gray rock, immediately underlying the Knox dolomite. It is the lowest and oldest rock formation exposed in the region under consideration. The limestone is interbedded with more or less shale. It is known in the region as the Flatwoods formation, because it underlies the flat, badly drained lands of the valleys. Thus it underlies Opossum Valley, as at North Birmingham, for two-thirds of its width; and east of Cemetery Ridge it has an outcrop more than a mile in width in the central part of the city of Birmingham, where its ledges can be seen here and there in the streets. Most of the limestone seen outcropping in Opossum Valley between Village Creek and the Louisville and Nashville Railroad is Conasauga. This outcrop wedges out a mile south of Wylam, and to the north it gradually tapers to a point and disappears beneath

the dolomite about 1 mile north of Greene station, on the Louisville and Nashville Railroad. The outcrop east of Cemetery Ridge extends northward as a narrow belt through East Lake, running to a point and disappearing beneath the dolomite one-half mile west of Hoffman. In Murphree Valley a belt of this limestone half a mile wide extends from Remlap to Chepultepec.

The Conasauga limestone can be readily distinguished from the overlying dolomite by the following differences: The limestone is blue or dark gray, without granular texture, and effervesces freely when treated with cold dilute acid; the dolomite is generally light gray with distinct granular texture and effervesces in cold dilute acid very feebly or not at all.

It is probable that the Conasauga formation in this region is not all limestone, but is composed of alternating layers of limestone and shale.

The Conasauga limestone is separated from the younger rocks on the west by a fault which has brought it into contact successively with all the overlying formations as high as the coal measures. The beds generally dip at a high angle. It seems probable that they are affected by minor folding or wrinkling to a considerable extent. Such wrinkling can be seen along the road from Dolcito to Tarrant Gap, and it probably occurs elsewhere as well. On account of such irregularities in the dip no reliable estimate of the thicknesss of the Conasauga limestone can be made. It seems hardly probable, however, that it is less than 1,000 feet, and it may be much greater. No use has been made of this limestone so far as known to the writer.

Below is an average analysis, by William E. Janes, of two samples from an old quarry near Wheeling, northeast of Bessemer. It was kindly furnished by Mr. A. Lodge, of the Woodward Iron Company:

Average analysis of Conasauga limestone from Wheeling quarry.

Silica (SiO_2)	1.20
Iron oxide and alumina ($Fe_2O_3+Al_2O_3$)	.49
Lime carbonate ($CaCO_3$)	89.03
Magnesium carbonate ($MgCO_3$)	8.04
Sulphur dioxide (SO_2)	.115

This rock is suitable for flux and for lime, but it contains too much magnesia for cement making. It would, however, manifestly be unsafe to draw any conclusions as to the general composition of this limestone from these two analyses.

The outcrop of the formation is always on low ground, little above drainage, and the dips are high, so that conditions for quarrying are very unfavorable. Since there is abundant material in the region of as good or even better quality and better situated for quarrying, there is little likelihood that this limestone will be utilized to any extent.

SAND-LIME BRICKMAKING NEAR BIRMINGHAM, ALA.

By Charles Butts.

The manufacture of sand-lime brick is rapidly approaching the proportions of an important industry in the United States, as it has been in Germany for the last ten or fifteen years. In the following brief discussion of the subject no effort is made to go into detail.

A sand-lime brick is essentially a mass of sand cemented by hydrous lime silicates. The sand may be either loose sand or pulverized sandstone. Sand and quicklime are thoroughly mixed in the proportion of 5 to 10 pounds of lime to 100 pounds of sand. The lime may be slaked to a putty or to a powder; or it may be ground dry and mixed with the sand, enough water being added to slake the lime. In any case the mixture should contain enough water to be plastic. The brick are molded and placed in a steam drying cylinder where they remain from seven to ten hours under a pressure of 115 to 160 pounds to the square inch, at a temperature of 170° to 185° C. It is believed by the advocates of sand-lime brick that this treatment results in the formation of lime silicates or lime hydrosilicate, by which the sand grains are firmly cemented together, making a brick of great strength. These brick can easily be made with a crushing strength of over 4,000 pounds per square inch and a tensile strength of over 200 pounds per square inch. The crushing strength and elasticity exceed that of some sandstones. The brick withstand severe freezing and thawing tests, as well as fire tests. With pure sand the color is white, but by the addition of various proportions of manganese or graphite, pink or gray brick can be made. It is claimed that these brick will make very rigid structures and that they are in every way safe and satisfactory building material. Both common and front brick are made. Their chief merits seem to be their white color and their somewhat lower cost of manufacture than that of clay or shale brick used for building fronts and for ornamental purposes.

The sand used for brick should be comparatively free from clay and feldspar, neither of which probably should exceed 10 per cent and even a smaller amount may be desirable. The best results appear to

be obtained from the use of high calcium, hot or fat lime, that is, lime made from limestone containing 85 to 100 per cent of calcium carbonate. Some magnesium carbonate may be present.

According to Peppel[a] the cost of production in this country, not including interest, depreciation, repairs, etc., varies from $3 to $4 per thousand and the selling prices vary, according to the locality, from $8 to $15 per thousand.

A few notes are appended concerning the plant near Sayreton, Ala., a village just north of Birmingham. This plant is owned and operated by the Birmingham Sand-lime Brick and Stone Manufacturing Company. The sand used here is derived from the sandstone outcropping along the crest of Sand Mountain. This sandstone lies near the base of the "Coal Measures." Its composition is shown by the following analysis:

Analysis of sandstone from Sand Mountain, Alabama.

Metallic iron (Fe)	0.50
Silica (SiO_2)	92.80
Alumina (Al_2O_3)	2.69
Lime (CaO)	.33
Magnesia (MgO)	.50
Moisture	.62

The sand from the pulverized rock is mixed by the Schwarz process with lime in the proportion of 70 pounds of lime to a cubic yard of sand with the addition of enough water to make the mass plastic. The material is then pressed dry and run into cylindrical driers, where the brick remain eight hours under a pressure of 160 pounds of steam. The brick are white and hard and have a crushing strength of 4,507 pounds per square inch. The daily capacity of the plant is 20,000 brick. The product is sold in Alabama, Georgia, and Mississippi, and there is a large local demand.

An unlimited supply of sandstone from the formation supplying the sand at Sayreton is to be had along Sand Mountain, Black Jack Ridge, and Shades Mountain, and also on Oak Mountain, east of Leeds. Sand from a lower Carboniferous sandstone lying between the Fort Payne chert and the Bangor limestone, which has an extensive outcrop in the region, would also be suitable for brickmaking, since it is nearly pure quartz sand. The quarry between Gate City and Irondale, from which glass sand has been taken, is in this sandstone. It makes Little Sand Mountain southwest of Trussville and the dikelike outcrop from Tarrant Gap to Mount Pinson, known as Rocky Row. It is conspicuous in Blount Valley. At Blount Springs it makes the sharp ridge just east of the hotel. It is possible that many of the sandstone strata in the coal measures would afford sand

[a] Peppel S. V., Bull. Geol. Survey Ohio No. 5, 1905, p. 78.

suitable for brick, since they appear to be made up mostly of quartz grains. There is an unlimited source of lime in the Bangor and Chickamauga limestones, described in the paper in this volume entitled "Limestone and dolomite in the Birmingham district, Alabama" (pp. 247–255).

For those who wish more detailed information on the subject the following references are given, taken mainly from Eckel's book, the first in the list:

ECKEL, E. C., Cements, Limes, and Plasters, 1905, pp. 130–147.

—— Lime and sand-lime brick: Mineral Resources U. S. for 1905, pp. 1003–1006.

GOWDY, J. K., Sand bricks in France: U. S. Consular Reports, No. 1547, January, 1903.

KITCHELL, W., Lime-brick manufacture: Second Ann. Rept. New Jersey Geol. Survey, 1856, pp. 107–108.

MARSTON, A., Tests of sand-lime and sand-cement brick and concrete building blocks: Eng. News, vol. 51, 1904, pp. 387–389.

MASON, F. H., Calcareous brick and stone manufacture in Germany: Daily U. S. Consular Reports, No. 1765, October 3, 1903.

OWEN, W., Patent lime and sand block: Jour. Soc. Chem. Industry, vol. 19, 1899, p. 147.

PEPPEL, S. V., The manufacture and properties of artificial sandstone: Trans. Am. Ceramic Soc., vol. 4, 1903; Eng. News, vol. 49, 1903, pp. 70–73.

—— Further contributions to the manufacture of artificial sandstone or sand brick: Trans. Am. Ceramic Soc., vol. 5, 1903.

—— Sand-lime brick industry: Mineral Resources U. S. for 1903, pp. 866–882.

—— The manufacture of artificial sandstone or sand-lime brick: Bull. Geol. Survey of Ohio, 4th ser., No. 5, 1905.

This is probably the most complete original treatise on the subject published in this country. It brings the subject down to January 1, 1905.

ROCHMANOW, ——, Basic fire-proof bricks: Thonindustrie Zeitung, vol. 27, p. 108; abstract in Jour. Soc. Chem. Industry, vol. 22, 1903, p. 421.

SCHWARZ, ——, Sand bricks. Abstract in Jour. Soc. Chem. Industry, vol. 21, 1902, pp. 1183–1184.

WOLFF, L. C., Bricks of lime and sand: Thonindustrie Zeitung, vol. 23, pp. 854–859; abstract in Jour. Soc. Chem. Industry, vol. 19, 1899, p. 48.

ANON., The Schwarz drying and mixing machine for manufacturing lime-sand brick: Eng. News, vol. 49, 1903, p. 179.

SURVEY PUBLICATIONS ON LIME AND MAGNESIA.

In addition to the papers listed below, which deal principally with lime, magnesite, etc., further references on limestones will be found in the lists given on pages 245–246 and 360 under the heads "Cements" and "Building stone," respectively.

BASTIN, E. S. The lime industry of Knox County, Maine. In Bulletin No. 285, pp. 393–400. 1906.

HESS, F. L. Some magnesite deposits of California. In Bulletin No. 285, pp. 385–392. 1906.

RIES, H. The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut. In Seventeenth Ann. Rept., pt. 3, pp. 795–811. 1896.

STOSE, G. W. Pure limestone in Berkeley County, W. Va. In Bulletin No. 225, pp. 516–517. 1904.

YALE, C. G. Magnesite deposits in California. In Mineral Resources U. S. for 1903, pp. 1131–1135. 1904.

GYPSUM, PLASTERS, ETC.

GYPSUM IN NORTHWESTERN NEW MEXICO.

By Millard K. Shaler.

INTRODUCTION.

The field work on which the following notes are based was carried on in connection with a reconnaissance survey of the Durango-Gallup coal field during the fall of 1905.

Extensive deposits of gypsum occur at many places in New Mexico, particularly in the southeastern and northwestern parts of the Territory,[a] but they are developed only at Ancho, on the line of the Rock Island Railroad, where a plaster mill has been in operation for several years.[b]

The gypsum along the western base of the Sierra Nacimiento was known at least as early as 1849, when Simpson[c] mentioned its occurrence in his journal. In 1859 Newberry[d] saw these deposits and described them as "immense masses of snowy gypsum." Cope[e] in 1875 also refers to extensive deposits of gypsum along the western base of Sierra Nacimiento. Cope regarded these deposits as Jurassic, but Newberry was inclined to the belief that they are of Triassic age.

It is highly probable that these beds were formed by precipitation of salts from sea water evaporated in a partly or entirely inclosed basin. This seems to have been the opinion of Cope, who says:[f]

> In the badland tract I obtained satisfactory evidence of the lacustrine character of the formation, a point of much importance, inasmuch as the nature of these beds has remained very obscure up to the present time. The evidence consists of numerous specimens of bones and teeth of two or three species of saurians, one of which at least was of terrestrial habits, according to our present knowledge.

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[a] Herrick, H. N., Gypsum deposits in New Mexico; Bull. U. S. Geol. Survey No. 223, pp. 89-99.

[b] Eckel, E. C., Gypsum and gypsum products in 1905: Mineral Resources U. S. for 1905, pp. 1105-1115.

[c] Simpson, James H., Journal of a military reconnaissance from Santa Fe, N. Mex., to the Navajo country, pp. 25-26.

[d] Newberry, J. S., Exploring expedition from Santa Fe to junction of Grand and Green rivers, 1859, p. 177.

[e] Cope, E. D., U. S. Geog. Survey W. 100th Mer., vol. 4, pp. 1-13.

[f] Loc. cit., p. 9.

STRATIGRAPHY AND STRUCTURE.

The Sierra Nacimiento consists of a north-south trending series of even-crested ridges and serrated peaks. It is approximately 35

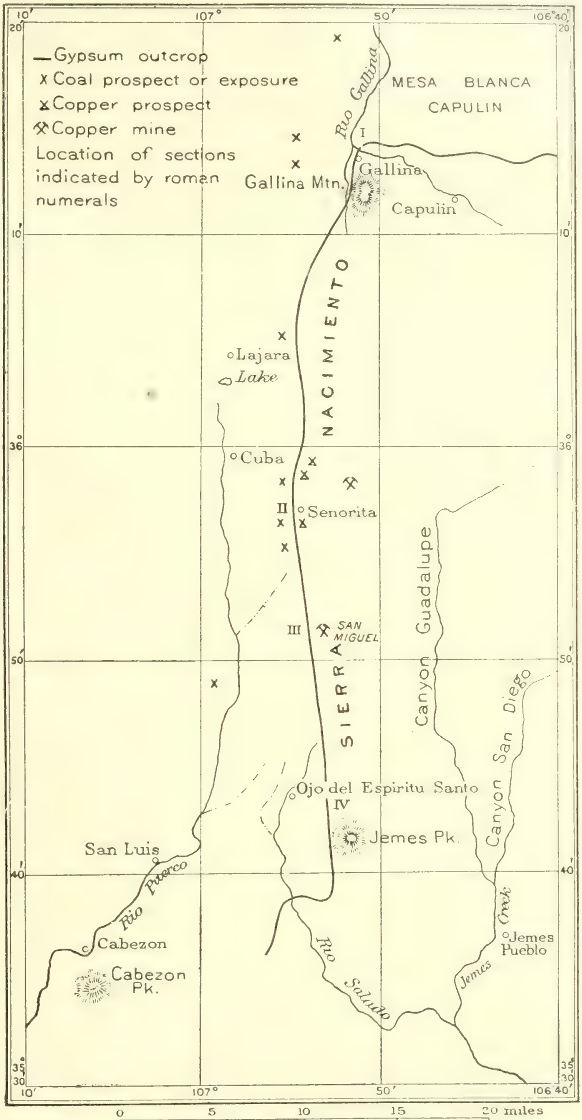

FIG. 9.—Sketch map showing line of outcrop of gypsum bed.

miles long, extending from the latitude of Gallina, N. Mex., on the north to the latitude of Cabezon on the south. Gallina Mountain marks the northern and Jemes Peak the southern terminus of the range. These peaks rise to an elevation of more than 9,000 feet above

sea level, their summits lying 3,000 feet above the lowland area that extends westward from the base of the mountains. The main mountain mass is made up of pre-Carboniferous (pre-Cambrian?) granites, schists, and gneisses, which are overlain in patches by Carboniferous limestone and sandstone and Permo-Carboniferous rocks and flanked on all sides by Mesozoic strata. The Mesozoic rocks are tilted at a high angle along the western front of the range, dipping steeply westward away from the mountain mass except where locally overturned.

The gypsum deposits along the western base of the range lie near the top of the "Red Beds" series. They are apparently at all places underlain by a bed of bright yellow, poorly consolidated sand, and are overlain by dark shales and yellowish brown sandstone of Dakota or Jurassic age, from which they are occasionally separated by a thin bed of limestone. The Mesozoic rocks are tilted generally westward throughout the length of the mountain range, but at its extremities, at the northern and southern ends of the gypsum outcrop, as mapped, the strike of the beds changes to a northeast-southwest direction and the dip becomes northwesterly and less steep. A fault, whose extent and relations are not yet clearly understood, trends north-south between the vicinity of Cuba and a point east of the southern end of the Nacimiento Range. This fault appears to involve only the Cretaceous rocks overlying the Dakota formation.

GYPSUM DEPOSITS.

During the hasty examination of the deposits time was not available to measure sections in the pre-Cretaceous rocks except at great intervals along the outcrop, and the measurements made were not all accurate. At Gallina, on Gallina Creek, near the northern limit of the gypsum outcrop as here mapped, a bed of massive white gypsum outcrops within the limits of the village, where it has been, to a very limited extent, quarried and burned, the product being used by the inhabitants for plastering their adobe houses. The deposit is readily accessible and is mined by open cut. The gypsum bed may be traced eastward from Gallina for many miles, as it outcrops along Gallina Creek in the southward-facing bluff of Mesa Blanca Capulin. The rocks in this mesa lie almost flat, having a very low northwesterly dip, about equal in grade to the fall of the creek. A section of the lower Mesozoic rocks containing the gypsum deposits is given below.

Section of rocks in Mesa Blanca Capulin.

	Feet.
Dakota red sandstone	80
Red and green shale (Dakota or Jurassic)	300
Gypsum	40+
Yellow, poorly consolidated sand	50
Red sandstone (Jurassic-Triassic)	300+

Farther south, between Gallina and Senorita, the same gypsum bed was observed at many places, but its thickness and its relations to the overlying and underlying rocks were not particularly noted. East of Lajara the bed, if present, is completely covered by flat-lying Tertiary sediments, which overlap the Mesozoic section from the west. This condition probably exists at several localities between Gallina and Senorita.

At Senorita the rocks that include the gypsum dip very steeply to the west. The gypsum bed outcrops above a limestone bed 50 feet in thickness, from which lime has been burned for local use. So far as known, the gypsum has not been utilized at Senorita, where it outcrops, striking north-south about one-fourth mile west of the post-office. The company that has a copper smelter situated at Senorita has opened a 6-foot coal bed which outcrops about one-half mile west of the gypsum outcrop. This bed furnishes a good grade of bituminous or subbituminous coal and its outcrop parallels the gypsum outcrop throughout its extent as mapped. The presence of this coal should do much to hasten development of the gypsum bed at this point. As will be seen from the section that follows, the gypsum bed has a thickness of 54 feet at Senorita.

Section of rocks exposed at Senorita.

	Feet.
Mesaverde coal measures, containing 6-foot coal bed	
Mancos shale	2,500+
Dakota sandstone (shale and sandstone at base of unknown age)	600
Gypsum; massive, white	54
Limestone, white, crystalline	50
Shale, red and greenish drab	600
"Red Beds" sandstones and shales (copper bearing at base)	750

About 3 miles west of San Miguel copper mine, at present abandoned, a bed of massive white gypsum 60 feet thick outcrops, dipping nearly due west at an angle of 40°. Here the gypsum is overlain by a bed of limestone 40 feet thick. The following section shows the relations of the underlying and overlying rocks to the gypsum.

Section of rocks exposed at San Miguel mine.

	Feet.
Dakota sandstone and shale at base (shale may be Jurassic)	100+
Crystalline limestone	40
Massive white gypsum	60
Light pinkish sandstone, red shale at base	80
Light pinkish sandstone, copper bearing	40
Red sandstone, with some shale interbedded (Jurassic-Triassic)	300+
Pre-Carboniferous (pre-Cambrian?) granite.	

The gypsum deposit at this point is easily accessible by the wagon road to Bernalillo, and could be mined over an extensive area, at first by open cut and later, as necessity demanded it, by slope or incline.

It is reported that the gypsum has been used locally for making plaster for a number of years, although no workings were seen by the writer.

A partial analysis by W. T. Schaller, of the United States Geological Survey, of a sample taken from the gypsum bed at the surface at this point is as follows:

Analysis of gypsum from west of San Miguel copper mine.

Calcium oxide (CaO)	34.24
Sulphur trioxide (SO_3)	46.61
Water	18.89
Insoluble residue	.18
Loss	.08

This analysis shows that the gypsum at this point is practically pure. It contains about 2.5 per cent of calcium oxide, more than can be in combination with the sulphur trioxide present. It is likely that this excess is in combination with CO_2, which has been included as water and loss.

At the head of a tributary to Rio Salado, about 3 miles southeast of Ojo del Espiritu Santo, at an elevation between 7,500 and 8,000 feet, the gypsum bed reaches a maximum thickness of about 100 feet. Near the mountains the bed is conformable with the underlying rocks, which dip westward at an angle of 70°. Within a short distance, however, across the dip, the gypsum bed becomes very flat, conforming with the dip of the overlying Dakota(?) formation. The relations here are not plain, but it is believed that the dip of the underlying Mesozoic strata decreases westward an equal amount. As a consequence of this flattening away from the mountains and the presence of a valley heading near this locality, a large area of gypsum is exposed and can be mined to advantage by open cut. It should be accessible by a wagon road built at slight expense up the valley of a tributary of Rio Salado. In appearance the gypsum is identical with that analyzed from near San Miguel mine. In the section it will be noticed that the limestone bed, which was 50 feet thick at Senorita, is absent here.

Section of rocks exposed near Ojo del Espiritu Santo.

	Feet.
Alternating shales and sandstones (Dakota?)	500 +
Massive, white gypsum	100
Shales and argillaceous sandstone	[a] 250
Red sandstone (Jurassic-Triassic)	200
Pre-Carboniferous (pre-Cambrian?) granite	

The gypsum bed outcrops continuously for several miles in a zone extending northward from the locality just described. It dips westward at an angle of 50° and extends to a point 4 miles farther south.

[a] The exposure in the upper part was too poor to enable the writer to affirm or deny the presence of the yellow sand below the gypsum.

where, the strike abruptly changing to a nearly east-west direction, the line of outcrop crosses the Cabezon-Albuquerque wagon road and then courses southwestward for an unknown distance. Where the gypsum outcrop crosses the wagon road the bed dips gently west-northwest. At this point it is covered by a thin bed of shale and could probably be exposed over a considerable area by stripping. It is here, apparently, that Simpson[a] observed gypsum and salt deposits. Salt was not seen by the writer, but it is undoubtedly present in the vicinity in some quantity, for the Rio Salado, whose head tributaries drain the area, is exceedingly salty. The section exposed at this point is in all respects similar to that measured at the locality just described. Here the yellow, unconsolidated sand bed, 50 feet thick, underlies the gypsum.

RÉSUMÉ.

As has been already noted above, the deposits are practically inexhaustible and are accessible by wagon road, but railroad facilities are lacking. The nearest railroad station is Bernalillo, on the Atchison, Topeka and Santa Fe Railroad. This place is 25 miles distant from the gypsum deposit last described—so far that a wagon haul is quite out of the question under present conditions. It is not thought likely that the deposits will be worked on a commercial scale until the gypsum beds of the territory that are situated nearer railroad lines have been practically exhausted or until the demand for gypsum products greatly increases. It is not at all improbable, however, that a railroad line will soon be built into the area, the promoters having in view primarily the development of the coal and copper resources of the region, a description of which has been given in other Survey publications.[b] The presence of the coal beds will do much to promote the development of the gypsum industry in this region, for the gypsum may be burned on the ground cheaply. The analysis given above shows that the gypsum is of exceptional purity where the sample was taken. Throughout its occurrence its physical characteristics are similar, and in so far as one may be guided by appearance it is everywhere of similar purity. The gypsum is suitable for any purpose to which gypsum is adapted.

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[a] Loc. cit.

[b] Schrader, F. C., The Durango-Gallup coal field of Colorado and New Mexico: Bull. U. S. Geol. Survey No. 285, 1905, pp. 250–251. Lindgren, W., and Graton, L. C., A reconnaissance of the mineral deposits of New Mexico: Bull. U. S. Geol. Survey No. 285, 1905, p. 86. Lindgren, W., Graton, L. C., Gordon, C. H., and Schrader, F. C., Reconnaissance of the mineral deposits of New Mexico: Prof. Paper U. S. Geol. Survey, in preparation.

SURVEY PUBLICATIONS ON GYPSUM AND PLASTERS.

The more important publications of the United States Geological Survey on gypsum and plasters are included in the following list:

ADAMS, G. I., and others. Gypsum deposits of the United States. Bulletin No. 223. 123 pp. 1904.

BOUTWELL, J. M. Rock gypsum at Nephi, Utah. In Bulletin No. 225, pp. 483–487. 1904.

ECKEL, E. C. Salt and gypsum deposits of southwestern Virginia. In Bulletin No. 213, pp. 406–416. 1903.

ORTON, E. Gypsum or land plaster in Ohio. In Mineral Resources U. S. for 1887, pp. 596–601. 1888.

RICHARDSON, G. B. Salt, gypsum, and petroleum in trans-Pecos Texas. In Bulletin No. 260, pp. 573–585. 1905.

SIEBENTHAL, C. E. Gypsum of the Uncompahgre region, Colorado. In Bulletin No. 285, pp. 401–403. 1906.

——— Gypsum deposits of the Laramie district, Wyoming. In Bulletin No. 285, pp. 404–405. 1906.

SURVEY PUBLICATIONS ON SALT, BORAX, AND SODA.

The more important publications of the United States Geological Survey on the natural lime, sodium, and potassium salts included in this group are the following:

CAMPBELL, M. R. Reconnaissance of the borax deposits of Death Valley and Mohave Desert. Bulletin No. 200. 23 pp. 1902.

——— Borax deposits of eastern California. In Bulletin No. 213, pp. 401–405. 1903.

CHATARD, T. M. Salt-making processes in the United States. In Seventh Ann. Rept., pp. 491–535. 1888.

DARTON, N. H. Zuñi salt deposits, New Mexico. In Bulletin No. 260, pp. 565–566. 1905.

DAY, W. C. Potassium salts. In Mineral Resources U. S. for 1887, pp. 628–650. 1888.

——— Sodium salts. In Mineral Resources U. S. for 1887, pp. 651–658. 1888.

ECKEL, E. C. Salt and gypsum deposits of southwestern Virginia. In Bulletin No. 213, pp. 406–416. 1903.

——— Salt industry of Utah and California. In Bulletin No. 225, pp. 488–495. 1904.

HILGARD, E. W. The salines of Louisiana. In Mineral Resources U. S. for 1882, pp. 554–565. 1883.

KINDLE, E. M. Salt resources of the Watkins Glen district, New York. In Bulletin No. 260, pp. 567–572. 1905.

PACKARD, R. L. Natural sodium salts. In Mineral Resources U. S. for 1893, pp. 728–738. 1894.

RICHARDSON, G. B. Salt, gypsum, and petroleum in trans-Pecos Texas. In Bulletin No. 260, pp. 573–585. 1905.

YALE, C. G. Borax. In Mineral Resources U. S. for 1889–1890, pp. 494–506. 1902.

CLAYS AND CLAY PRODUCTS.

PROPERTIES AND TESTS OF FULLER'S EARTH.[a]

By John T. Porter.

GEOLOGY AND ORIGIN.

Practically all workable deposits of fuller's earth are of secondary origin, having been redeposited in sedimentary series. Residual deposits are also known, for example, in Saxony, where the fuller's earth is found in situ derived from gabbro. As is to be expected from its origin, the deposits are most frequently found in the Tertiary formations. Thus the well-known beds at Quincy, Fla., are of the Miocene epoch, and the earths in South Carolina belong to the Eocene and Neocene formations. The extensive deposits of South Dakota are also of Tertiary age, but in which division I am unable to state. On the other hand, certain British deposits are stated[b] to belong to the lower greensand (Lower Cretaceous), and Dana[c] mentions the "fuller's earth group" as a subdivision in oolite of the Jurassic period.

Gabbro, diorite, diabase, and basalt are mentioned by different writers as rocks from which fuller's earth is derived. It will be noticed that these rocks are all similar in their nature and belong to either the hornblendic or basaltic series. Their characteristic mineral constituents are the augites and hornblendes, with the feldspars less prominent: the zeolites magnetite, ilmenite, olivine, and other minerals may also be present. The subjoined table gives a list of minerals which from lithologic considerations would seem likely to be found in fuller's earth. This list embraces not only the abovementioned minerals, but also the hydrous aluminum silicates or clay minerals which may result from their decomposition. For convenience in reference, the chemical composition and certain physical properties are also tabulated.

[a] The work on which this report is based was carried out in the laboratory and at the expense of Mr. Charles Catlett, of Staunton, Va., in connection with an investigation of the subject for private persons. Mr. Catlett has kindly placed the results of this work at the disposal of the Survey, and as they seem to represent the first detailed series of comparative tests on such materials it has been decided to publish them in the present bulletin.—E. C. E.

[b] Nineteenth Ann. Rept. U. S Geol. Survey, pt. 6, continued, 1898, p. 408.

[c] Dana, J. D., Manual of Geology, 1895, p. 775.

TABLE 1.—*Minerals likely to be found in fuller's earth.*

MINERALS OF CLAYS AND SOILS.

Name.	Specific gravity.	Hardness.	Crystallization.	Effect of acids.	Authority.[a]
Muscovite	2.80	2.00	Monoclinic	Not attacked	A, B.
Biotite	2.90	2.50	do		A.
Phlogopite	2.80	2.50	do		A.
Pectolite	2.70	5.00	do	Decomposed by HCl	A, B.
Laumontite				do	B.
Prehnite	2.90	6.00	Orthorhombic	Partly decomposed by acid	A, B.
Natrolite	2.20	5.00	do	Decomposed by H_2O and acid	A, B.
Analcite	2.20	5.00	Isometric	Decomposed by HCl	A, B.
Datolite	3.00	5.00	Monoclinic		A.
Chabazite	2.10	4.50	Hexagonal		A.
Stilbite	2.10	3.50	Monoclinic	Decomposed by HCl	A, B.
Heulandite	2.20	3.50	do	do	A, B.
Orthoclase	2.50	6.00	do	Insoluble	A, B.
Microcline	2.50	6.00	Triclinic		A.
Albite	2.60	6.00	do	Not attacked	A, B.
Oligoclase	2.60	6.00	do	Slightly attacked	A, B.
Labradorite	2.70	5.00	do	do	A.
Anorthite	2.70	6.00	do	Decomposed by HCl	A, B.
Hornblende	3.10	6.00	Monoclinic	Slightly attacked	A, B.
Tremolite	3.00	6.00	do	do	A, B.
Actinolite	3.10	6.00	do	do	A, B.
Glaucophane	3.10	6.00	do		A.
Diallage					
Enstatite	3.20	5.50	Orthorhombic		A.
Hypersthene	3.50	6.00	do		A.
Jefferisite					
Ripidolite					
Penninite	3.90	2.00	Monoclinic		A.
Prochlorite	2.90	2.00	do		A.
Spinel	3.60	8.00			A.
Hydrargillite				Soluble in HCl and H_2SO_4	B.
Bauxite	2.50	2.00	Amorphous		A.
Diaspore	3.40	7.00	Orthorhombic	Insoluble in acids	A, B.
Quartz	2.60	7.00	Hexagonal	Not attacked	A, B.
Opal	2.00	6.00	Amorphous		A.
Calcite	2.70	3.00	Hexagonal	Soluble	A.
Dolomite	2.90	3.50	do	do	A.
Gypsum	1.50	2.30	Monoclinic		A.
Apatite	3.20	5.00	Hexagonal	Soluble	A.
Marcasite	4.90	6.00	Orthorhombic	Insoluble	A.
Pyrite	5.00	6.00	Isometric	do	A.
Limonite	3.60	3.00	Amorphous	Soluble	A.
Magnetite	5.20	6.00	Isometric	Slowly soluble	A.
Hematite	5.10	3.00	Hexagonal	Soluble	A.
Siderite	3.80	3.50	do	do	A.
Rutile	4.20	6.00	Tetragonal	Insoluble except after long concentration in H_2SO_4.	A, B.
Ilmenite	4.80	5.50	Hexagonal		A.
Pyrolusite	4.80	2.00	Orthorhombic	Soluble	A.
Olivine	3.30	6.50	do	Decomposed by HCl and H_2SO_4	A, B.
Vesuvianite	3.40	6.50	Tetragonal	Partly decomposed by HCl	A, B.
Epidote	3.30	6.50	Monoclinic	Slightly attacked by HCl	A, B.
Zoisite	3.30	6.00	Orthorhombic	Partly decomposed by HCl	B, C.
Allanite	4.00	5.50	Monoclinic		A.
Andalusite	3.20	3.00	Orthorhombic	Insoluble in acids	A, B.
Staurolite	3.70	7.00	do	Not attacked	A, B.
Fibrolite	3.20	6.00	do		A.
Cyanite	3.60	6.00	Triclinic	Insoluble in acids	A, B.
Scapolite	2.70	6.00	Tetragonal		C.
Nepheline	2.60	6.00	Hexagonal	Decomposed by HCl	B, C.
Talc	2.80	1.00	Monoclinic	Not attacked	B, C.
Serpentine	2.60	3.00	do	Decomposed by acids	B, C.
Wollastonite	2.90	4.50	do	Decomposed by HCl	B, C.

[a] A=Eakle, A. S., Mineral Tables, 1904. B=Comey, A. M., Dictionary of Solubilities. C=Dana, J. D., Manual of Mineralogy, 1857.

TABLE 1.—*Minerals likely to be found in fuller's earth*—Continued.

CLAY MINERALS.

Name.	Specific gravity.	Hardness.	Crystallization.	Effect of acids.	Authority.[a]
Kaolin	2.60	2.00	Monoclinic	Insoluble in HCl; decomposed by H_2SO_4.	A, B.
Pholerite	2.60	2.00	do	Insoluble in HNO_3	B.
Halloysite	2.00		Amorphous	Decomposed by acids	B.
Rectorite			Monoclinic		
Newtonite	2.40		Rhombohedral		
Allophane	1.90	3.00	Amorphous	Soluble in dilute acids	B.
Smectite					
Malthacite					
Passau porcelain clay.					
Razoumoffskine					
Montmorillonite				Not decomposed by HCl; decomposed by H_2SO_4.	
Pyrophyllite	2.90	1.50	Monoclinic	Not decomposed by H_2SO_4	B.
Anauxite					
Cimolite					
Clagerite					
Kollyrite				Decomposed by all acids and H_2O	

Name.	Formula.	Composition.		
		Silica.	Alumina.	Water.
Kaolin	$Al_2O_3.2SiO_2.2H_2O$	46.4	39.7	13.9
Pholerite	$2Al_2O_3.3SiO_2.4H_2O$	39.3	45.0	15.7
Halloysite	$Al_2O_3.2SiO_2.3H_2O$	43.5	36.9	19.6
Rectorite	$Al_2O_3.2SiO_2.H_2O$	50.0	42.5	7.5
Newtonite	$Al_2O_3.2SiO_2.5H_2O$	38.5	32.7	28.8
Allophane	$Al_2O_3.SiO_2.5H_2O$	28.2	40.5	31.3
Smectite	$Al_2O_3.7SiO_2.l_212H_2O$	57.0	13.8	29.2
Malthacite	$Al_2O_3.7SiO_2.116H_2O$	52.2	12.4	35.4
Passau porcelain clay	$4Al_2O_3.9SiO_2.l_212H_2O$			
Razoumoffskine	$Al_2O_3.4SiO_2.7H_2O$	51.5	21.7	26.8
Montmorillonite	$Al_2O_3.3SiO_2.3H_2O$	53.7	30.3	16.0
Pyrophyllite	$Al_2O_3.4SiO_2.H_2O$	64.2	30.3	5.0
Anauxite	$Al_2O_3.4SiO_2.3H_2O$	60.8	25.6	13.6
Cimolite	$2Al_2O_3.9SiO_2.6H_2O$	63.5	23.9	12.6
Glagerite	$2Al_2O_3.3SiO_2.6H_2O$			
Kollyrite	$3Al_2O_3.SiO_2.9H_2O$			
Schrotterite		12.0	46.3	36.2

[a] A=Eakle, A. S., Mineral Tables, 1904. B=Comey, A. M., Dictionary of Solubilities, 1896.

When the rocks from which fuller's earth is derived are kept in view, it seems to me that the inference may be fairly drawn that it results from the decomposition of the hornblendes and augites, rather than of the feldspars, as is the case with ordinary clays. This view is also supported by the fact that magnesia is almost invariably a prominent constituent of fuller's earth, in which it averages much higher than in ordinary clays. (See Table 2.)

Now, it is well known that the decomposition of the feldspars tends toward the production of kaolin and the crystalline aluminum hydrosilicates, and it seems possible that the hornblendes and augites, on the other hand, may have a tendency to decompose into the amorphous silicates. I will endeavor to show later that fuller's earth contains these amorphous aluminum hydrosilicates, and if the truth of this theory could be proved much light would be thrown on the whole question of the origin of fuller's earth and its relation to the clays.

The literature on this subject is so fragmentary and so widely distributed that references having a direct bearing on it are difficult to

find. It is quite possible, indeed probable, however, that some of the work recently done on the action of water on rock powders[a] will be found on close study to afford an explanation of the formation of fuller's earth. The following table comprises a number of analyses of fuller's earth, obtained from the sources indicated:

TABLE 2.—*Analyses of fuller's earth from various sources.*

[Calculated to dry state.]

No.	Locality.	SiO_2.	Al_2O_3.	H_2O.	Fe_2O_3.	CaO.	MgO.	Alkalies.	Other elements.	Total.	Authority.[a]
1	Arkansas	64.38	17.29	6.95	8.27	1.91		1.83	n. d.	100.63	A.
2	....do	63.19	18.76	7.57	7.05	2.46		1.71	n. d.	100.74	A.
3	Ocala, Fla	39.66	30.00	13.11	3.46	0.87	0.70	.45	P_2O_3 6.00 FiO_2 1.37 Organic 3.90	99.52	B.
4	Gadsden, Fla	67.31	11.07	8.25	2.61	2.60	3.32	1.01	n. d.	96.17	C.
5	Mount Pleasant, Fla.	62.27	11.76	10.00	7.43	1.89	3.59	n. d.	n. d.	96.94	C.
6	Norway, Fla	59.02	11.88	11.13	7.14	6.48	3.24	n. d.	n. d.	98.89	C.
7	River Junction, Fla.	55.05	22.88	10.42	7.47	4.77	.43	n. d.	n. d.	100.92	C.
8	Decatur, Ga	72.00	10.76	6.00	2.65	3.34	4.36	n. d.	n. d.	99.11	C.
9	Enid, Okla. (glacialite).	50.36	33.38	12.00	3.31	......	......	.88	TiO_2 tr. Organic tr.	99.93	D.
10	Custer, S. Dak	57.00	17.37	9.50	2.36	3.00	3.03	n. d.	Volatile 5.85	98.11	E.
11	.....do	63.50	14.97	10.70	4.48	2.40	2.88	8.32	n. d.	107.25	D.
12	.....do	71.28	14.33	4.30	2.48	.33	1.20	n. d.	n. d.	93.92	D.
13	.....do	55.45	18.58	8.80	3.82	3.40	3.50	n. d.	Volatile 5.35	98.90	E.
14	Fairburn, S. Dak	68.23	14.93	6.20	2.15	2.93	.87	n. d	n. d.	96.31	E.
15	.....do	60.16	10.38	7.20	14.87	4.96	1.71	n. d.	n. d.	99.28	E.
16	.....do	67.00	5.00	15.00	12.00	n. d.	n. d.	n. d.	n. d.	99.00	D
17	.....do	56.18	23.23	11.45	1.26	5.88	3.29	n. d.	n. d.	101.29	E.
18	.....do	60.10	17.30	8.29	4.10	4.16	2.61	2.16	n. d.	98.72	C.
19	Hermosa, S. Dak	55.40	27.70	13.00	1.80	2.30	.70	1.08	n. d.	101.98	D.
20	England	44.00	23.06	24.95	2.00	4.08	2.00	n. d.	n. d.	100.09	C.
21	.....do	44.00	11.00	n. d.	10.00	5.00	2.00	5.00	n. d.	77.00	C.
22	Nutfield, England (blue earth).	52.81	6.92	14.27	3.78	7.40	2.27	1.74	P_2O_5 .27 SO_3 .05 NaCl .05	88.56	D.
23	Nutfield, England (yellow earth).	59.37	11.82	13.19	6.27	6.17	2.09	1.84	P_2O_5 .14 SO_3 .07 NaCl .14	100.10	D.
24	Reigate, England	53.00	10.00	24.00	9.75	.50	1.25	n. d.	n. d.	98.50	C.
25	Woburn sands, England (yellow earth).	55.48	19.16	6.75	11.78	3.10	3.71	n. d.	n. d.	99.98	B.
26	Woburn sands, England (blue earth).	60.90	18.34	4.89	10.22	2.36	1.52	1.72	n. d.	99.95	B.

[a] A=Branner, J. C., Cement materials of southwest Arkansas: Trans. Am. Inst. Min. Eng., vol. 27, 1898, pp. 42-63.

B=Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6, continued, 1898, pp. 655-656.
C=Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 3, continued, 1896, pp. 876-880.
D=Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 5, continued, 1897, pp. 1351-1359.
E=Ries, H., fuller's earth of South Dakota: Trans. Am. Inst. Min. Eng., vol. 27, 1898, pp. 333-335.

TESTS BEARING ON THE NATURE OF FULLER'S EARTH.

ANALYSES.

The analyses made in the course of this investigation have for convenience been grouped together and will be found in Table 3. A few results have been calculated or estimated, and the figures so derived are marked with a small c. The analyses were made by the customary methods, which hardly need explanation. All results were calculated to a dry basis. CO_2 was determined gravimetrically. Combined water is ignition minus CO_2, and possibly includes a little organic carbonaceous matter.

[a] Cushman, A. S., Effect of water on rock powders: Bull. Bur. Chemistry, U. S. Dept. Agr., No. 92, 1905.

TABLE 3.—*Analyses of fuller's earth, clay, and pipe clay.*

CALCULATED TO 100 PER CENT.

	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	CO_2.	H_2O.	P_2O_5.	Total.
Owl fuller's earth:[a]									
Original earth	48.20	17.80	2.09	10.84	3.33	7.93	8.91	1.20	100
Insoluble in dilute HCl	74.20	12.90	1.94	c.05	n.d.	....	9.28	n.d.	90.37
Insoluble in dilute HCl and NaOH	70.70	15.80	1.70	.08	n.d.	.....	9.36	n.d.	97.64
Insoluble in dilute HCl and soluble in NaOH	79.72	10.52	Tr.	....	n.d.	.....	9.58	n.d.	99.82
Insoluble in concentrated HCl	90.88	3.40	...	c.05	......	.....	5.14	n.d.	99.47
Insoluble in H_2SO_4 and NaOH	91.10	4.35	1.09	3.46	......	.....	......	n.d.	100
Insoluble in H_2SO_4 and soluble in NaOH	83.17	2.81	......	14.02	......	......	......	n.d.	100
Soluble in NaOH alone	82.4	17.60	......	......	......	......	n.d.	n.d.	100
Fairbank fuller's earth:[b]									
Original earth	59.41	19.90	7.14	3.29	2.90	.04	6.75	.06	99.29
Insoluble in dilute HCl	66.60	19.20	5.54	.48	1.67	....	7.11	n.d.	100
Insoluble in dilute HCl and soluble in NaOH	18.80	n.d.	n.d.	n.d.	n.d.	....	n.d.	n.d.	n.d.
Insoluble in concentrated HCl	86.80	5.95	.90	.27	c.27	....	1.55	n.d.	c 98.74
Insoluble in H_2SO_4	92.95	3.66	1.83	n.d.	n.d.	.....	n.d.	n.d.	98.44
Insoluble in H_2SO_4 and NaOH	75.75	13.79	1.67	c.80	n.d.	....	n.d.	n.d.	92.01
Soluble in NaOH alone	11.89	n.d.	n.d.	n.d.	n.d.	.....	n.d.	n.d.	n.d.
Eimer & Amend fuller's earth:[c]									
Original earth	60.20	21.00	7.80	2.80	2.60	n.d.	7.50	n.d.	99.10
Insoluble in concentrated HCl	75.30	17.20	5.04	Tr.	2.46	......	n.d.	n.d.	100
Insoluble in H_2SO_4	91.95	3.67	Tr.	.61	.76	......	3.67	n.d.	100.66
Insoluble in H_2SO_4 and NaOH	73.06	12.00	......	5.44	n.d.	......	n.d.	n.d.	90.50
Clay:[d]									
As received	61.62	22.82	4	.52	n.d.	n.d.	8.06	n.d.	97.02
Insoluble	92.48	3.53	......	.14	n.d.	n.d.	n.d.	n.d.	96.01
Pipe clay:[c]									
As received	46.10	41	.	.	....	n.d.	12.82	n.d.	99.92
Insoluble in H_2SO_4	97.06	2.94	.....	.....	.....	n.d.	n.d.	n.d.	100

PER CENT OF ORIGINAL EARTH.

Owl fuller's earth:[a]									
Original earth	48.20	17.80	10.84	3.33	7.93	8.91	1.20	2.09	100.30
Insoluble in dilute HCl	48.45	8.43	c.03	1.41		6.06	n.d.	1.27	65.33
Insoluble in dilute HCl and NaOH	25.24	5.64	c.03	n.d.	.	3.31	n.d.	.69	35.67
Insoluble in dilute HCl and soluble in NaOH	22.72	2.80	......	n.d.		c2.72	n.d.	Tr.	28.24
Insoluble in concentrated HCl	48.20	1.85	c.02	n.d.	.	2.78	n.d.	....	c 52.85
Insoluble in concentrated HCl and NaOH	c9.16	n.d.	n.d.	n.d.		n.d.	n.d.	n.d.	9.22
Insoluble in concentrated HCl and soluble in NaOH	39.04	n.d.	n.d.	n.d.	....	n.d.	n.d.	n.d.	n.d.
Insoluble in H_2SO_4 and NaOH	9.22	.44	.35	.	....	.	n.d.	.12	10.12
Insoluble in H_2SO_4 and soluble in NaOH	39.69	1.32	6.59	n.d.	...	n.d.	n.d.	....	c 47
Soluble in NaOH	8.57	1.83	....	n.d.	....	n.d.	n.d.	....	c 10.4
Fairbank fuller's earth:[b]									
Original earth	59.41	19.9	3.29	2.90	.04	6.75	.06	7.14	c 99.29
Insoluble in dilute HCl	59.41	17.36	.43	1.51	.....	6.40	n.d.	5.02	c 90.13
Insoluble in dilute HCl and soluble in NaOH	16.92	n.d.	n.d.	n.d.	..	n.d.	n.d.	n.d.	n.d.
Insoluble in concentrated HCl	59.41	4.10	.19	c.19	......	3.07	n.d.	.62	c 68.9
Insoluble in concentrated HCl and soluble in NaOH	53.21	n.d.	n.d.	n.d.	......	n.d.	n.d.	n.d.	n.d.
Insoluble in H_2SO_4	59.21	2.33	n.d.	n.d.	......	n.d.	n.d.	1.17	63.68
Insoluble in H_2SO_4 and NaOH	5	.91	c.05	n.d.	......	n.d.	n.d.	.11	6.58
Soluble in NaOH	11.89	n.d.	n.d.	n.d.	......	n.d.	n.d.	n.d.	n.d.
Eimer & Amend fuller's earth:[c]									
Original earth	60.20	21	2.80	2.60	n.d.	7.50	n.d.	7.80	99.1
Insoluble in concentrated HCl	60.40	13.56	Tr.	1.97	......	n.d.	n.d	4.03	c 79.96
Insoluble in H_2SO_4	60.23	2.40	.40	.50	......	2.40	n.d.	Tr.	65.55
Insoluble in H_2SO_4 and NaOH	5.37	.98	.40	n.d.	......	n.d.	n.d.	......	7.35
Soluble in NaOH	10.38	n.d.	n.d.	n.d.	......	n.d.	n.d.	n.d.	n.d.
Soluble in Na_2CO_3	2.60	n.d.	n.d.	n.d.	......	n.d.	n.d.	n.d.	n.d.
Clay:[d]									
As received	61.62	22.82	4	.52	n.d.	n.d.	8.06?	n.d.	97.02
Insoluble in H_2SO_4	61.50	2.35	....	.1	n.d.	n.d.	n.d.	n.d.	66.5
Soluble in Na_2CO_3	.25?	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pipe clay:[c]									
As received	46.10	41	.....	.....	......	n.d.	12.82	n.d.	99.92
Insoluble in H_2SO_4	46.2	1.1	......	......	......	n.d.	n.d.	n.d.	17.6

[a] Sample from Owl Cigar Co., Quincy, Fla.
[b] Sample from N. K. Fairbank Co., Chicago, Ill.
[c] Sample from Eimer & Amend, New York, N. Y.
[d] Residual limestone clay from Staunton, Va.

PHYSICAL TESTS.

Plasticity is defined as that property which permits clay to be molded in any desired form when wet, the shape being retained when dry.[a] F. F. Grout[b] says that "Plasticity may be considered as involving two variable factors—(1) amount of possible flow before rupture; (2) resistance to flow or deformation."

According to either of these definitions the four samples of fuller's earth which I have tested are most decidedly plastic, in spite of the fact that nonplasticity is given as one of the distinguishing qualities of this material by almost every writer on the subject.

In making these tests small pats of wet earth were allowed to air dry, and portions were heated to redness to note their behavior. It was found that the fuller's earths require much water to bring them to the plastic state, apparently more than the kaolin, although the quantity used was not measured. The fuller's earth also formed a much more sticky mass than the other materials tried, and had a more soapy or greasy feel. Table 4 gives the results of these tests in convenient form.

TABLE 4.—*Physical properties of fuller's earths, etc.*

Material.	Relative amount of water to bring to plastic state.	Plasticity.	Coherence when dry.	Strength when burned.
Owl fuller's earth [a]	Most	Very great	Very strong	Very hard and strong.
Fairbank fuller's earth [b]	do	do	do	Do.
Eimer & Amend fuller's earth [c]	do	do	do	Do.
Queen fuller's earth [d]	Much	do	do	Do.
Kaolin [e]	do	do	do	Do.
Iron ore	Least	Least	Much less	
Fairbank fuller's earth insoluble in H_2SO_4.	Less	Less	Very soft	Did not crumble, but very soft.

[a] Sample from Owl Cigar Co., Quincy, Fla.
[b] Sample from N. K. Fairbank Co., Chicago, Ill.
[c] Sample from Eimer & Amend, New York, N. Y.
[d] Sample from Queen & Co., Philadelphia, Pa.
[e] Pure china clay from Augusta County, Va.

OIL TESTS.

In making the oil tests 50 c. c. of cotton-seed oil were introduced into a stout comparison tube of about 120 c. c. capacity. This was then placed in an oil bath and heated to a temperature of 220° F.; 2.5 grams of the earth to be tested were then poured into the tube, which was at once removed from the oil bath, closed with a rubber stopper, and shaken for five minutes. At the end of this time the contents were poured into a creased filter in a hot-water funnel, and the filtered oil was received in a tube protected from the light by a cardboard case. This protection was found necessary because certain

[a] Ries, H., Clays and clay industries of New Jersey: Final Repts. New Jersey Geol. Survey, vol. 6, 1904, p. 81.

[b] Clays, Limes, and Cements, West Virginia Geol. Survey, 1906, p. 41.

oil samples bleached out very rapidly after treatment if exposed to light, and the amount of bleaching varied in different samples. The method of comparison adopted was as follows: Twenty-one samples of oil were selected which had stood in the light long enough to have reached a condition of stability, and which showed a progressive range of color from the lightest to the darkest oil on hand. These samples were contained in glass vials of uniform size, were kept in a dark box, and were numbered from 1 to 21, No. 1 being Fairbank's standard white oil, which had stood in the light several years and No. 21 Fairbank's crude yellow oil, kept in the dark so that it had not lost any of its depth of color. The samples tested were then placed in similar vials, compared with the standards against a sheet of white paper, and the number of the standard most nearly agreeing with it in shade was taken as its color value. This comparison was always made immediately after filtration, before the oil had been exposed to light. After standing over night in the dark the sample was compared again, and a third time after standing in the light for two weeks. This method of comparison proved very satisfactory, and there was no evidence of any change in the standards on keeping. The only weakness of the method lies in the fact that the members of the color series do not vary uniformly in the amount of color contained, and hence these comparisons can give no information as to the absolute percentage of color removed.

The results of the oil tests are grouped in Table 5, which does not include, however, a number of the first tests that were considered unreliable. It should be noted that standards Nos. 19, 20, and 21 are all crude yellow oils untreated, and that no bleaching action is indicated with any certainty unless the color of the treated sample falls to 18 or less.

TABLE 5.—*Results of oil tests of fuller's earth and other materials.*

No.	Material.[a]	Color value of oil. Immediately after filtration.	Color value of oil. After standing 12 hours in dark.	Color value of oil. After standing 2 weeks in light.
	FULLER'S EARTH.			
	Untreated:			
1	Owl	12	12	2
2	Fairbank	12	12	3
3	Eimer & Amend	13	12	2
4	Earth from Quincy, Fla.	13	13	3
	Dried:			
5	Eimer & Amend dried at 140° C.	12	12	2
6	Fairbank, ignited at red heat for 1½ hours	19	19	18½
	Extracted with hot dilute HCl (1:2):			
7	Owl	13	12	2
8	Fairbank	11	11	1½

[a] Fuller's earths: Owl, from Owl Cigar Co., Quincy, Fla.; Fairbank, earth at present used by N. K. Fairbank Co., Chicago, Ill., received in June, 1906; Eimer & Amend, from Eimer & Amend, New York, N. Y. Pipe clay (sample from Eimer & Amend), nearly pure kaolinite, as shown by the rational analysis—kaolin, 91.51; orthoclase, 7.61; quartz, 0.88—which is calculated from the analysis given in Table 3. Clay, a residual limestone clay from a bank in Staunton, Va. Analyses of most of these materials will be found in Table 3 (p. 272).

TABLE 5.—*Results of oil tests of fuller's earth and other materials*—Continued.

No.	Material.	Color value of oil. Immediately after filtration.	After standing 12 hours in dark.	After standing 2 weeks in light.
	FULLER'S EARTH—continued.			
	Extracted with concentrated HCl:			
9	Owl	16	....	14
10	Fairbank	12	....	2
11	Eimer & Amend	5	5	Less than 1.
	Decomposed with concentrated H_2SO_4:			
12	Owl, heated 6 days	16	....	....
13	Fairbank, heated 6 days	14	14	7
14	Eimer & Amend, heated	15	15	13
15	Do	16	....	12
16	Do	13	....	3
	Extracted with alkalies:			
17	Fairbank, extracted with 5 per cent NaOH	19	....	18½
18	Fairbank, extracted with 5 per cent NaOH, rewashed	18	....	17
19	Fairbank, extracted with 5 per cent NaOH, fine part	18	....	16
20	Fairbank, extracted with Na_2CO_3, half-saturated	15	....	12
21	Eimer & Amend, extracted with 5 per cent NaOH	15	16	14
22	Eimer, extracted with concentrated Na_2CO_3	10	10	2
	Extracted with acids and alkalies:			
23	Owl, extracted with dilute HCl and NaOH	19	....	18½
24	Fairbank, extracted with dilute HCl and NaOH	16½	....	15
25	Eimer & Amend, extracted with H_2SO_4 and Na_2CO_3	17	....	15
	Miscellaneous treatments:			
26	Fairbank, extracted with NH_4OH and dried at 130° C	17	25	15
27	Fairbank, exposed to NH_3 gas for 24 hours	18	....	17
28	Fairbank, saturated with alum solution and dried	15	....	8
	PIPE CLAY.			
29	Untreated	19	....	....
30	Dried	17	....	16
31	Decomposed with H_2SO_4	16	16	14
32	Ground to ¾ gr	18	....	16
	CLAYS.			
33	Settlings or sandy part	15	15	11
34	Fine part	14	14	3
35	Decomposed with H_2SO_4	17	....	15
36	Extracted with Na_2CO_3	14	....	3
37	With 1 per cent HCl and just enough NH_4OH to neutralize	14	14	6
38	Exposed to NH_3	18½	18½	18
39	With 4 per cent boiled starch	14	14	3
	ARTIFICIAL ALUMINAS.			
40	Precipitated with NH_4OH and dried at 150° C	18	18	16
41	Precipitated with NH_4OH and washed in alcohol and ether	18	18	16
42	No. 46 reboiled and dried at 120° C	16	16	15
43	Boiled 30 hours and dried at 130° C	18	....	17
44	No. 42 only partially dried	21	....	20
45	Ignited	19	18	17
46	Precipitated with 75 per cent powdered glass	18	....	17
47	Precipitated from KOH solution by CO_2	18½	....	18
	ARTIFICIAL SILICAS.			
48	Precipitated from Na_2SiO_3, washed in alcohol and ether, and air dried	18	....	16
49	Precipitated and ignited	20	....	18
50	From decomposition of Na_2SiO_3 by H_2SO_4	21	....	....
	OTHER SUBSTANCES.			
51	Limestone, 100-mesh	19	....	14
52	Siliceous iron ore	18	....	16
53	Emery flour	21	21	20
54	Powdered glass	21	21	20
55	Bone ash	21	21	20
56	Carbo leached with 1 per cent HCl	15	....	10
57	Calcium phosphate precipitated	20	20	19
58	Aluminum phosphate precipitated	19	19	18
59	Ferric hydrate precipitated	20	20	17

NATURE OF FULLER'S EARTH.

THEORIES OF OTHER WRITERS.

Almost as many suggestions have been advanced concerning the nature of fuller's earth as there are writers on the subject, but apparently none of them are based on anything more than an inspection of the ultimate analyses. I will now take up these theories and study them in the light of my experiments.

Dana[a] states that fuller's earth has for its base the mineral smectite, and possibly also malthacite. Although it is not so stated in the passage quoted, the inference is that he considers these minerals the cause of the bleaching power. In order to test the truth of this theory it is necessary to have at hand formulæ of smectite and malthacite, and these I have calculated as here described. Dana (as quoted by Ries[a]) gives the following analyses of impure minerals:

Analyses of smectite and malthacite.

	SiO_2.	Al_2O_3.	H_2O.	Fe_2O_3.	CaO.	MgO.
Smectite	51.21	12.25	27.89	2.07	2.13	4.89
Malthacite	50.17	10.66	35.83	3.15	.25	....

I have considered the iron, lime, and magnesia as impurities, and have recalculated the analysis on the basis of silica, alumina, and water = 100. The result is as follows:

Recalculated analyses of smectite and malthacite.

	SiO_2.	Al_2O_3.	H_2O.
Smectite	56.0	13.5	30.5
Malthacite	51.9	11.0	37.1

The formulæ corresponding most nearly to these figures are for smectite $Al_2O_3.7SiO_2.12H_2O$, and for malthacite $Al_2O_3.7SiO_2.16H_2O$, and the percentage composition for these formulæ should be the following:

Composition corresponding to formulæ for smectite and malthacite.

	SiO_2.	Al_2O_3.	H_2O.
Smectite	57.06	13.78	29.16
Malthacite	52.18	12.40	35.42

These figures are used in all calculations and in the table of minerals (p. 270).

[a] Quoted in Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 3, continued, 1896, p. 876.

To return now to Dana's theory of fuller's earth, it is evident that it will not stand since the discovery of American deposits having a comparatively low percentage of combined water. Such earths could not possibly have as their base either smectite or malthacite, although they might contain very small quantities of these minerals. For example, take analysis 18 of Table 2 (p. 271), representing a sample of earth from Fairburn, S. Dak. Calculating the water in this entirely to smectite gives 28.1 per cent smectite, requiring 16 per cent silica and 3.8 per cent alumina, and leaving a large balance of silica and alumina, as well as impurities, to be calculated to anhydrous minerals.

Again, my analyses of Fairbank and Owl fuller's earths (Table 3, p. 272) show that it is utterly impossible for these earths to contain even moderate amounts of smectite or malthacite, in view of the small quantities of quartz and undecomposible anhydrous silicates shown. This point is very clearly brought out when the calculation of a rational composition is attempted. Another point which argues against the presence of smectite and malthacite in American fuller's earths is the fact that these earths retain much and in some cases all of their efficiency after treatment with strong acids. Although I have not been able to find any statement that smectite and malthacite are decomposed by sulphuric acid, still it is very probable that they are so attacked, owing to their large percentage of combined water.

It is interesting to note in passing that an inspection of the table of minerals shows that where determined the ease of decomposition by acids of the hydrous aluminum silicates is probably a direct function of the percentage of alumina and combined water, the water probably having the greater effect.

Although it may be regarded as settled that smectite and malthacite are not contained to any extent in most American fuller's earths, and hence are not essential to the bleaching power, still it is probably true that smectite forms the basis of many foreign earths. It is of course impossible to calculate rational composition with any certainty from ultimate analysis alone. However, the following composition has been calculated from analysis 24 of Table 2 (p. 271), principally to show the possibility that this earth contains smectite as a base:

Rational analysis of fuller's earth from Reigate, England.

	Total.	SiO_2.	Al_2O_3.	H_2O.	Fe_2O_3.	Alkalies, CaO and MgO.
Smectite	70	40	9.6	20.4		
Limonite	12.6			2.9	9.7	
Kaolinite	1.6	.9	.4	.3		
Augite	6.5	3.2				3.3
Quartz	8.9	8.9				
Organic matter	.4			.4		

Ries[a] states that fuller's earth probably contains much hydrous silica, the inference being that it is this constituent which gives it its distinctive qualities. A somewhat similar inference is perhaps to be drawn from the following quotation, referring to the Florida and Georgia earths:[b]

> This leads to the hypothesis that this earth probably originated in ordinary clay, which has received from interfiltering solutions an additional supply of silicic acid, which sometimes combined with the clay and occasionally was deposited as chert.

My analyses have confirmed Ries's statement that fuller's earth contains appreciable amounts of hydrous silica. (See Table 3, p. 272.) However, it is evident that if the bleaching power of fuller's earth is due to this hydrous silica, treatment of the earth with boiling carbonate or hydrate of soda, which removes the silica, should destroy this bleaching power. I have tried this experiment on several earths, and the result will be found in Table 5 (p. 275). It will be seen at once that although the results are not entirely concordant, yet there can be no doubt that fuller's earth retains at least a part of its efficiency after treatment by alkalies. It is also plain that carbonate of soda has a much less harmful action on the earth than the hydrate. As Fresenius and other authorities state that hydrous and amorphous silica are freely soluble in hot carbonate of soda, as well as in sodium hydrate, this difference can hardly be due to nonsolution of the silica by the carbonate, but is almost entirely due to partial decomposition of the earth by sodium hydrate. In this connection, I have noticed that sodium hydrate appears to extract considerable alumina as well as silica, but the carbonate does not. Fuller's earth after treatment with sodium hydrate is left in a very gelatinous condition and is extremely hard to filter and wash. For this reason it is possible that some of the samples treated retained considerable amounts of soluble salts after washing, although great pains were taken to remove them, and this may have had some influence on the results.

Another fact which might be used as an argument against this theory is that hydrous silica artificially prepared has but very slight bleaching powers. (See Table 5.) These results are naturally not conclusive, as the silicic acid occurring naturally may differ either physically or chemically, or both, from the artificial product.

On the other hand, some earths still retain a considerable portion of their bleaching power after decomposition by acids, consisting then of 80 per cent or more of silica; and from this it seems probable that hydrous silica when prepared in certain ways may have some small efficiency.

In conclusion, I think I am justified in stating, first, that hydrous silica does not of itself possess bleaching power, although it may at

[a] Ries, H., Fuller's earth of South Dakota: Trans. Am. Inst. Min. Eng., vol. 27, 1898, p. 333.
[b] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 6, continued, 1901, p. 591.

imes possess some efficiency as a result of existing in a certain physical condition; and, second, that it is certain that fuller's earth can not owe more than a small part of its peculiar properties to the presence of free silicic acid.

Sloan[a] makes the following suggestion concerning the mode of action of fuller's earth:

> Fuller's earth is now extensively employed in the bleaching of mineral, animal, and vegetable oils and fats. The alleged chemical bleaching in the process is highly questionable; its action more properly involves mechanical entanglement of the suspended coloring matter by the contained clay substance. * * * It is observed that where the alumina exceeds one-fifth of the amount of silica present the critical point is approximated beyond which an increase in the densely bedding aluminous matter prejudices filtration. The silica therefore serves to maintain the required porosity.

Sloan has here come very near to hitting the mark. He has evidently the right idea in mind, but has not gone deeply enough into the subject to state it in detail with clearness. The propriety of these remarks will become more clearly apparent later in this discussion; for the present I will only remark that it is important that the term "clay substance" be taken in its more general significance and not as synonymous with kaolin. Also, I must take exception to the implied statement that the bleaching power is dependent on and proportional to the alumina in the earth, as I have found that up to a certain point removal of the alumina is actually beneficial to the efficiency of the earth. (See results 8, 10, and 11, Table 5.)

I see no other suggestions as to the mode of action of fuller's earth proposed in any of the literature, but it is possible that some may consider extreme fineness of grain an explanation, and it may be worth while to combat this idea. Wheeler, I believe, has shown that most clays (and other minerals?) have some slight bleaching power, if very finely powdered, but no one has been able to procure any appreciable efficiency by such means. The few experiments I have made have given practically negative results, and, as shown later, any very slight increase in efficiency can be readily explained. Finally, it can be easily seen that it would be very difficult to explain the peculiar effects of acid on fuller's earth on the assumption that its bleaching action is due primarily to fineness.

In concluding this division the following quotation[b] seems of interest. The authors are chemists of the United States Internal-Revenue Office and undoubtedly have excellent facilities for consulting chemical literature.

> The color-absorbing power of fuller's earth is a most interesting subject which does not appear to have been investigated to any extent. Whether it is due to chemical or physical action, and the connection, if any, between the composition of the earth

[a] Sloan, Earle, Preliminary Report on Clays of South Carolina, South Carolina Geol. Survey, 1904, pp. 59-61.

[b] Crampton, C. A., and Simons, F. D., Detection of caramel in spirits and vinegar: Jour. Am. Chem. Soc., vol. 21, 1899, p. 355.

(which seems to be anything but uniform) and its effect upon various coloring matter should receive attention and would doubtless yield interesting and valuable results to investigation. If any work has been done along this line, no results have been published, as the journals make little or no mention even of the fact that fuller's earth possesses such properties.

COLLOIDS AND PECTOIDS.

A colloid is defined [a] as referring generally—

> to those bodies which pass into solution in water, but which will not while in solution pass through a parchment diaphragm, as substances in true molecular solution always will do. The word hydrogel given by Graham is used to refer to the jellied colloids as they originally coagulate from the hydrosols. * * * Ostwald says: "Colloidal substances exist in two modifications—the soluble and the coagulated or 'pectinized.'" We need another word to express this latter condition, and the word pectoid is truer to the Greek root (πηκτός) than pectinized.

A little later on I shall endeavor to show that the peculiar properties of fuller's earth are probably due to the presence of a group of aluminum hydrosilicates existing in the form of pectoids, as above defined, and with this object in view I will now give a short digest of the present knowledge of colloidal substances as far as I have been able to find it in the literature at my command.

Colloids and also pectoids exist among both organic and inorganic substances, ferric and aluminum hydroxides being familiar examples of the latter. With regard to the existence of these substances in the mineral world, the following references have been found:

Ladd,[b] quoting Le Chatelier, says:

> It may be said to be well established that there are various hydrosilicates of aluminum which differ in proportion, form, and structure, some being colloidal amorphous, and some crystalline.

Comey [c] speaks of halloysite as a colloidal clay.

Ries [d] found colloidal particles in some clays, and advanced the theory that plasticity was largely due to them.

Grimsley [e] speaks of the colloidal theory as explaining the plasticity of clays, and notes that most clays contain from 1 to 5 per cent of grains which will take stain from methylene blue, gentian violet, eosin, or fuchsine. He found that the addition of 0.08 per cent of agar-agar increased the plasticity of clay very markedly, also that the addition of precipitated alumina if used without filtering or drying

[a] Cushman, A. S., Effect of water on rock powders: Bull. Bur. Chemistry, U. S. Dept. Agr., No. 92, 1905, p. 12.

[b] Ladd, G. E., Preliminary report on a part of the clays of Georgia: Bull. Georgia Geol. Survey No. 6A, 1898, p. 15.

[c] Comey, A. M., Dictionary of Solubilities, 1896, p. 361.

[d] Ries, H., Clays and clay industries of New Jersey: Final Repts. New Jersey Geol. Survey, vol. 6, 1904, p. 83.

[e] Grimsley, G. P., Clays of West Virginia: West Virginia Geol. Survey, 1906, pp. 37, 46.

ad the same effect, but if air dried, no such increase was noted. He marks that a colloid which will soften in water after drying is needed.

Wiley[a] speaks of a colloidal constituent of the clay, designating by hat term that portion of the clay which remains suspended almost ndefinitely in pure water. He states that it is precipitated by brine, orming a gelatinous mass like the mixed hydrates of iron and alumina.

Cushman[b] finds that "the action of water on many rock powders esults in the formation of colloid films on the surface of the particles," nd expresses the opinion that the binding power of rock dust, clays, nd soils is due to the formation and presence of these films on the surace of crystalline or amorphous granules.

It will be noted from these extracts that the word colloid is very oosely employed by various writers, many of them using it where ydrogel or pectoid would be more correct, while some seem to conder it as synonymous with amorphous.

Colloids, or more properly pectoids, possess the property of being eadily stained by most organic coloring matters and of holding this olor in an insoluble form. A familiar example is the use of alumina s a mordant in cotton printing, and Cushman[c] states that orthoclase owder which has been wet ground to develop the pectoidal films takes p a brown stain from the Canada balsam used in mounting it for nicroscopic examination. On the other hand, it is well known that ertain amorphous substances, not pectoids, also possess this proprty—for example, charcoal and boneblack. Grimsley[d] states that fresh gelatinized silicic acid will easily stain; air-dried silicic-acid elly will take a stain with equal readiness." From his further remark hat the addition of the air-dried jelly injures the plasticity of clay, I nfer that this silicic acid had passed from the pectoid to the amorhous state. Samples of precipitated silica which I prepared acted in his way when dried in air or by washing with alcohol and ether.

Soils and clays have long been known to possess the property of absorbing certain materials, both gaseous and liquid. Wiley[e] quotes many experimenters on this subject and from his work the following notes are taken. Clay exhibits a selective absorption of certain salts, holding the basic ions and rejecting the acidic ions. Way succeeded in producing an artificial hydrated silicate possessing absorptive powers. Eichhorn found that natural hydrated silicates or zeolites acted in a similar manner, and others have shown that the absorptive power bears a close relation to the amount of soluble silicates present.

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[a] Wiley, H. W., Agricultural Analysis, vol. 1, Soils, 1894, p. 231.

[b] Cushman, A. S., Effect of water on rock powders: Bull. Bur. Chemistry, U. S. Dept. Agr., No. 92 1905, p. 12.

[c] Op. cit., p. 13.

[d] Grimsley, G. P., Clays of West Virginia: West Virginia Geol. Survey, 1906, p. 49.

[e] Wiley, H. W., Agricultural Analysis, vol. 1, Soils, 1894, p. 118.

Cushman[a] says:

Linder and Picton have shown that when a coagulated colloidal precipitate is formed in the presence of an electrolyte, a portion of the basic ions of the electrolyte is absorbed by or adsorbed on the pectoid matter in the form of hydroxide, while the acid ions remain free in solution. Many other investigators have checked this astonishing and interesting fact. * * * This absorptive power is in no sense of the word due to chemical combination, but seems to depend upon the fine submicroscopic porosity of the pectoid.

It can be seen that as a result of this power of pectoids, it is in general impossible to wash a preparation of this character entirely free from the salts with which it is formed. Linebarger[b] found it impossible to remove all the chlorine from colloidal ferric hydrate prepared from ferric chloride by dialysis.

Colloids and pectoids are destroyed by heat, in some cases probably by drying. Data on these points seem to be sadly lacking, and there is also lacking a closely drawn distinction between pectoids and those bodies which are amorphous without being colloidal in their nature. However, as a certain amount of water is essential to the colloidal state, heating to a point at which the combined water is driven off must in all cases destroy this state. Further, it is probably true that a substance is colloidal as long as it retains its power of jellying with water either throughout or on the surface only. That some pectoids, at least, retain their characteristic properties after drying is shown by Cushman's experiments, but it is probable that the colloidal nature of alumina and silicic acid is largely destroyed by drying and is not capable of restoration by subsequent digestion with water. Whether an oil could take the place of water in promoting the colloidal state in mineral substances is an open question, but it is certain that organic colloids exist in oils, and it does not seem impossible that some mineral colloids may also.

Jones[c] states that colloids diffuse very slowly as compared with crystalloids. As diffusion is due to osmotic pressure, this means that the osmotic pressure of substances in colloidal solution is very low. What bearing this interesting fact may have on the absorptive powers of colloids, I can not at present state, but it seems likely that they may be in some way connected.

A NEW THEORY.

The theory which I have devised to explain the peculiar properties of fuller's earth may be stated as follows:

1. Fuller's earth has for its base a series of hydrous aluminum silicates.

[a] Cushman, A. S., Effect of water on rock powders: Bull. Bur. Chemistry, U. S. Dept. Agr., No. 92, 1905, p. 15.

[b] Linebarger, C. E., On the rate of diffusion of colloids: Jour. Am. Chem. Soc., vol. 20, 1898, p. 376.

[c] Cushman, A. S., Effect of water on rock powders: Bull. Bur. Chemistry, U. S. Dept. Agr., No. 92, 1905, p. 251.

2. These silicates differ in chemical composition.

3. They are, however, similar in that they all possess an amorphous colloidal structure.

4. The colloidal structure is of a rather persistent form and is not lost on drying at a temperature of 130° C., or possibly higher.

5. These colloidal silicates possess the power of absorbing and retaining organic coloring matter, thus bleaching oils and fats.

I have used the word colloidal in this statement in its broadest sense—to cover the whole range of conditions expressed by the words colloid, pectoid, and hydrogel. It is my opinion that the word pectoid would most properly express the condition of the active constituents of fuller's earth, but it is not impossible that these may go into partial solution in oil and thus become true colloids.

It will be seen by a study of the table of oil tests (p. 274) that the effect of acids on the bleaching efficiency of fuller's earth is peculiar, some earths being much more affected than others. The Eimer & Amend earth is evidently the least affected; and the Owl the most. I find it difficult to explain this except on the assumption that these earths contain several different minerals varying in amount and in ease of decomposition by acids, the bleaching power also being dependent on these minerals. I have noted on page 277 that the ease of decomposition by acids is for this series of minerals (the hydrous aluminum silicates) probably a function of the percentage of alumina and water, and we should expect to find this approximately true of the three earths tested in this investigation. An inspection of the ultimate analyses shows this to be so in a general way, and the parallel is much more apparent when we consider that the Owl earth contains about 15 per cent of lime carbonate as an impurity. The analyses of the residues after treatment with the acids and alkalies also show that the constituent silicates of the earth vary in resistance to acids. The improvement in efficiency of certain of the earths by treatment with dilute acids I attribute to the removal of limonite, calcite, and possibly some hydrous alumina, which may exert a clogging effect on the active minerals. This treatment may also increase the amount or the efficiency of the colloidal substance, as Cushman points out [a] that certain salts and other substances possess the power of coagulating clay substance and increasing its binding power.

The wide variation in ultimate analysis which is exhibited in Table 3 (p. 272) and which persists even after recalculation eliminating impurities, is readily explained by this assumption of a series of similar minerals. Variation in bleaching power of various earths is also thus explained, and if we can assume that these minerals have vary-

[a] Cushman, A. S., Effect of water on rock powders. Bull. Bur. Chemistry, U. S. Dept. Agr., No. 92, 1905, pp. 19, 22.

ing preferences for different classes of organic colors, we have a possible explanation of the puzzling fact that some earths which are very efficient for vegetable oils are useless on mineral oils, and vice versa. As bearing on the probability of this last assumption, Crampton and Simons[a] find that fuller's earth absorbs much more color (caramel) from artificially colored spirits than from the natural, and remark that it appears to exert a selective action for some coloring matters.

In passing I wish to say that the possibility of the efficiency of fuller's earth being due to organic colloids has occurred to me, but after due consideration I decided that this theory was untenable, as any organic matter was almost certainly destroyed in several of the acid-treated earths which gave fairly good results on oil.

As the recent work of Cushman and others has practically proved that the plasticity and binding power of clays and rock powders is dependent on the existence of pectoids, the nonexistence of plasticity in fuller's earth would certainly be a stumbling block to my theory. However, as I have shown on page 273, the earths on which I have worked possess a most decided plasticity, and an investigation is needed to determine the correctness of the numerous statements to the contrary. The property which I noted, of taking up very large quantities of water before reaching the plastic state, is certainly an attribute of colloids, and the extreme greasy or soapiness of feel is not less so.

The action of high temperature in destroying the efficiency of fuller's earth (see oil test No. 6, Table 5, p. 274), although it does not of itself prove the presence of colloids, at least agrees well with that theory, as it is well known that the colloidal structure is destroyed by heat, whereas an amorphous structure is unaffected.

Fuller's earth in suspension in water, in common with other clays, is readily coagulated and settled by traces of acid or larger quantities of salts. Wiley[b] calls this fine suspended matter colloidal clay, and it probably does consist of kaolin particles which are more or less pectinized on the surface. I have noticed in washing fuller's earth after it has been treated with sodium hydrate that it settles readily during the first decantations; then, as the amount of sodium hydrate becomes less, a part refuses to settle, and that which does settle becomes more gelatinous and swells until it occupies a volume several times as large as the original. On adding a few drops of acid to neutralize the sodium hydrate the earth settles readily. On drying, however, the earth forms a hard, hornlike mass similar to precipitated alumina. I explain these facts as follows: It is well known that alka-

[a] Crampton, C. A., and Simons, F. D., Detection of caramel in spirits and vinegar. Jour. Am. Chem. Soc., vol. 21, 1899, p. 356.

[b] Wiley, H. W., Agricultural Analysis, vol. 1, Soils, p. 231.

lies prevent flocculation of colloids and that acids and neutral salts promote it. This explains the nonsettlement of the earth. As for the gelatinization, it is evident that the strong alkali has the power of partially decomposing the earth and of converting the compact, resistant pectoids into a softer form that requires more water and is perhaps between a pectoid and a soluble colloid and similar to precipitated alumina.

Colloids are known to possess the power of taking up organic colors from solution (see p. 282), and the analogy with fuller's earth is so apparent as to excite surprise that it has not been studied from this point of view before. It has even been known that pectoids could extract colors from oils and resins as well as aqueous solutions. This I regard as a strong point in favor of the colloidal theory, although by itself it does not, of course, constitute a proof.

The power of colloids to absorb certain salts, or at least the basic ions of these salts, has been known a long time. It is also possessed to a degree by certain amorphous substances having a fine porous structure, such as charcoal and boneblack. Fuller's earth has this property to a marked degree. In fact, its use has been proposed to remove the lime from boiler water.[a] I have found that after it has absorbed ammonia or salts it loses a great part of its efficiency in bleaching oils. From this I infer that the bases are absorbed in a similar manner to the coloring matter of oil, and occupy the pores which otherwise would hold the color.

It has been pointed out that these absorbent materials have a selective action on the salts, absorbing the unlike ions and discarding the ions of like chemical nature. If colors in oil solution are absorbed in the same manner as salts in aqueous solution, analogy would lead to the supposition that fuller's earth would exert a selective action for certain classes of coloring matter and, moreover, that the earths themselves would differ in their selection of colors according as they are more or less acidic in composition. We find this entirely in accordance with the facts.

I have noticed in the course of my oil tests that on the same sample of oil different materials give products varying greatly in shade, the main color being in some tests of a yellow and in others of a green tint. Is it not likely that the oil contains several compounds of varying chemical nature, and that the earths or other materials used in bleaching extract them in ratios proportional to their own basicity or acidity? I have been unable to obtain any exact data on this point from my results, owing to the difficulty of following these slight changes in tint with the unaided eye. A tintometer would be needed if this line of investigation were to be followed out.

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[a] Mineral Industry, vol. 8, 1900, p. 219.

I believe that the reason for using heat in bleaching oils is that the lessened viscosity of the oil when heated allows the molecules of color to come into better contact with the particles of earth. Possibly, however, the beneficial result is partially due to the expulsion of water or air from the submicroscopic pores of the pectoid surface, thus making room for the coloring substance.

The table of oil tests (p. 275) shows that pipe clay, which is nearly pure kaolin, has some slight bleaching power. This is in line with the colloidal theory, taken in connection with Cushman's experiments on kaolin, in which he found that the kaolin grains were coated with a thin layer of pectoidal substance. This coating should be sufficient to give the kaolin the slight bleaching power it was found to have.

Tests Nos. 31 and 32 show that the kaolin is improved in bleaching efficiency by drying and also by decomposition with sulphuric acid. According to the colloidal theory, the improvement on drying is possibly due to the expulsion of the excess of water from the thin pectoid film on the surface of the crystals. The treatment by sulphuric acid, however, entirely decomposes the kaolin and leaves an amorphous silica, the excess of water being removed by the dehydrating action of the acid. It will be noted that the silica from the pipe clay does not vary much in efficiency from those samples prepared from fuller's earth in the same manner, especially when the latter have been thoroughly decomposed. It is also of interest to note that the silica from kaolin giving a color value of 16 does not differ very much from that prepared by precipitation and washing with alcohol and ether, value 18.

The limestone clay, which I found had a very considerable bleaching power, was probably in a more pectoidal state than the kaolin, and it is evidently to be expected that all gradations of bleaching power will be found in the various clays.

This same idea will apply to the fine mineral powders which Wheeler discovered to have a slight bleaching action. I do not know whether or not his powders were wet ground. If so, pectoidal substances were certainly contained in them. If ground dry, their efficiency is probably due to the increased surface action of amorphous particles.

At this point it seems necessary to examine into the difference, if any, in the mode of action of colloids and amorphous substances. It has been pretty well proved that the decolorizing power of charcoal and bone char (amorphous substances) is due to their exceedingly small "submicroscopic pores." These pores seem to be exceptionally well developed by certain forms of carbonaceous matter, but probably exist to a greater or less extent in all forms of finely divided amorphous matter. This, I take it, explains the small but uniform efficiency of such materials as precipitated and dried silica and alumina, and, as before noted, may also explain the results which Wheeler obtained with very finely pulverized materials. It is evident that the

slightest trace of sintering on material of this sort would close up these minute pores, and no doubt this is the cause of the destruction of the decolorizing power by ignition. (See tests Nos. 47 and 51, Table 5, p. 275.)

The mode of action of colloidal substances is probably very similar, even though the body of material containing the pores is of so different a nature. As before noted, many investigators have found that pectoidal substances possess the power of absorbing the basic ions of salts into their "fine submicroscopic pores," and there is no reason to think that the ions of coloring matter are held in any different way.

However, I must confess that I do not feel very clear in my mind as to the exact state or characteristics of what I have called the efficient pectoids. So little that is really definite is known on the subject that it is very difficult to draw a hard and fast line between colloids and amorphous bodies. Possibly all intermediate states between the soluble colloid and the most insoluble amorphous substance exist. If this is the case, it will lead to many interesting speculations. For example, it is possible that the more nearly a substance approaches the purely colloidal state the greater affinity it will have for coloring matter; but in the case of oil bleaching this state will be limited by the necessity of increased water in the softer colloids. At some intermediate point the maximum efficiency for oils would be found. The difficulty of preparing alumina without including a large excess of water is evidently the cause of my failures with that substance. We know that alumina has a strong affinity for coloring matter in aqueous solutions and very probably it would act with equal efficiency on oil, if it could be prepared without the water. It seems likely that the drying to a horny mass is an attribute of the softer and more highly hydrated colloids. Silicic-acid jelly when dried forms such a mass, but if it is first washed with alcohol and ether (which removes the excess of water) it dries to a white pulverulent powder, still, however, containing much combined water. It will be noted (see test No. 50) that when so prepared it has a slight efficiency. Fuller's earth also when treated with sodium hydrate swells, softens, and apparently takes up much water, forming a softer colloid. On drying it acquires the hornlike characteristics of dried alumina and loses considerable efficiency. (See also p. 286.) Another possible explanation of the action of dilute acids in increasing the efficiency of some earths occurs to me here. May not the acids decompose and remove the very soft and hydrous colloids and thus prevent their drying up and clogging the efficient particles? Another query in the same line: Might not strong drying decrease the efficiency of some earths that contain a larger proportion of the softer colloids, and would not a considerable variation in resistance to heat be found if many earths were tested? There is evidently room for much research along these lines.

I come now to a very interesting phase of my subject, although I have not studied it to any extent—namely, the bleaching action of light on oils. A study of the tables reveals an exceedingly significant fact. The after bleaching (or bleaching due to the action of light) appears to be much greater in the more efficiently bleached samples than in those which were only slightly bleached. I say "appears to be," because my color scale, although comparatively correct, is not absolutely so. In other words, the absolute percentage of coloring matter in the samples will not vary in the same amount from number to number. However, even if we allow for this, it seems almost certain that this after bleaching can not be altogether due to the chemical action of the light on the coloring substance, for in that case all samples should bleach a uniform amount. It seems necessary, therefore, to look elsewhere for the cause of this action, and as yet I have been unable to devise a satisfactory hypothesis.

It is evident that the colloidal theory is most susceptible of proof by means of microscopic work, but for lack of an instrument of sufficiently high power I have been able to do but little in this direction. Such results as were obtained, however, tend to confirm this theory.

Fuller's earth, dry (Fairbank No. 2), appears to be made up of a mass of small amorphous mossy particles that look something like lumps of half-dried alumina and seem to contain many tiny air bubbles. By transmitted light many small plates are seen. Some grains that are not plates are also visible, and a very few grains of a color varying from deep red to reddish yellow. Some particles have the look of small rings or groups of rings. I believe this to be due to the presence of transparent crystalline plates which have commenced to alter to an opaque substance around the edge. Fuller's earth treated with sulphuric acid also shows these rings. Kaolin shows extremely fine particles that are not mossy looking, and although these particles are so fine that their form can not be distinguished, yet their sharpness of outline and noncoherence point toward the crystalline structure.

Limestone clay shows large quartz grains, mossy lumps, like ferric hydrate, and large grains that are transparent in places, but are apparently covered with a brown mossy substance, like ferric hydrate.

Most of the other materials tested were also examined under the microscope, but nothing of any great significance was noted.

PRACTICAL APPLICATION OF COLLOIDAL THEORY.

If, as I anticipate, further investigation establishes the fact that there is a well-defined relationship between the rational composition of fuller's earth and the class of coloring matters which it removes most efficiently (see pp. 268, 284), there will evidently be afforded to chemists a means of predicting the value of fuller's earth and the class of work for which it is best adapted, on the basis of analysis. A little

study is needed to determine simple methods of rational analysis, but to judge from my experiments with acid treatment it is not likely to be a difficult problem.

These experiments also suggest the possibility of considerably increasing the bleaching efficiency of fuller's earth by treatment with dilute acids or similar means. There is no doubt that this can be done, but further investigations are needed to find more favorable conditions and to show whether the process can be made sufficiently economical for commercial use. It is also probable, as I have already pointed out (p. 287), that fuller's earth may vary in resistance to heat and in the degree of dryness needed. A close study of this phase of the subject might show how the preparation of the earth affects its bleaching qualities and point the way to an increased efficiency.

Finally, we come to the possibility of creating an artificial bleaching agent capable of doing the work of fuller's earth. I have no doubt whatever that many common clays can be found which possess a certain amount of bleaching power and which by proper treatment can be given an efficiency equal to fuller's earth. I am more skeptical as to the practicability of treating a neutral or nearly neutral body so as to make it an efficient bleaching agent. It is possible that future work may discover some artificial pectoidal body which will possess the same resistance to drying as the active pectoids of fuller's earth. In that case I can see no reason why it should not be possible to impregnate a kaolin or other porous medium with this substance and make of it an artificial earth. I am of the opinion that some such substance may be found among the organic colloids, although the single test I made along this line (test No. 41) was barren of result.

RATIONAL COMPOSITION OF FULLER'S EARTH.

Table 6 gives the approximate rational composition of the fuller's earths on which I have worked, as calculated from the analyses given in Table 3 (p. 272). The calculations are based on the percentages of silica, alumina, and water soluble and insoluble in the different strengths of acids, and I believe they come somewhere near the truth. It will be noticed that the figures do not exactly balance with the ultimate analyses, but they are probably as close as could be expected.

TABLE 6.—*Rational analyses of fuller's earth.*

Mineral.	Total.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	CO_2	H_2O	P_2O_5
OWL.									
Apatite	2.62				1.42				1.20
Calcite	16.82				9.42		7.40		
Magnesite	1.01					0.48	.53		
Montmorillonite	32.04	17.21	9.70					5.13	
Free hydrous silica	5.46	5.00						.46	
Iron oxides	.82			0.82					
Magnesia (?)	1.24					1.24			
Anauxite	24.41	14.84	6.25					3.32	
Augite, etc	5.90	1.93	1.41	1.15		1.41			
Feldspar and quartz	9.73	9.22	.44	.12					
	100.00	48.20	17.80	2.09	10.84	3.13	7.93	8.91	1.20
FAIRBANK.									
Apatite	.14				.08				.06
Free hydrous silica	11.97	11.90						.07	
Prehnite (?)	10.16	4.43	2.54		2.75			.44	
Other zeolites	2.07	.57			.11	1.39			
Iron oxides	2.12			2.12					
Anauxite	45.88	27.90	11.74					6.24	
Augite, etc	19.76	9.61	3.30	4.91	.43	1.51			
Quartz and feldspar	7.43	5.00	2.32	.11					
	99.53	59.41	19.90	7.14	3.29	2.90	.04	6.95	.06
EIMER & AMEND.									
Free hydrous silica	10.88	10.38						.50	
Iron oxides	3.80			3.80					
Zeolites, etc	7.22	2.00	1.44		2.80	.67		.31	
Anauxite	29.44	20.25	6.00					3.19	
Augite, etc	14.55	4.56	4.52	4.00		1.47			
Cimolite	27.78	17.64	6.64					3.50	
Quartz and feldspar	8.27	5.37	2.40			.50			
	101.86	60.20	21.00	7.80	2.80	2.64	n. d.	7.50	n. d.

CLAYS OF THE BIRMINGHAM DISTRICT, ALABAMA.

By Charles Butts.

INTRODUCTION.

The area here designated the Birmingham district covers about 1,000 square miles lying, in the main, north of Birmingham, Ala. In it are located a number of brickworks, utilizing local deposits of clay and shale. This paper is based on work done in the field by Chester W. Washburne, William F. Prouty, E. M. Dawson, jr., and the writer. Information drawn from published reports has been acknowledged in the proper place.

CLAY.

The clay is sedimentary and occurs either as a surficial deposit or as the underclay of coal seams. So far as known the only important superficial deposit of clay in this area occurs along Turkey and Cunningham creeks, south and east of Morris. This clay has been worked to a considerable extent for brickmaking at De Soto, on the Moss property, but the plant has not been in successful operation in recent years. The clay here is reported to be 10 to 12 feet thick, and shows the following section:

Section at Moss brickworks, De Soto.

	Ft.	In.
Gray sandy loam	1	0
Sandy clay	3	9
Layer full of ferruginous and sandy fragments	0	6
Clay stained with iron to bottom	5+	0

The entire thickness of the deposit is used. The bricks made from this clay are of a good, red color and are said to be of excellent quality, but to shrink a good deal in drying.

The clay in this locality is reported to occur in irregular patches of unknown shape and extent as far down Turkey Creek as the bridge south of Morris. Clay was noted along the Louisville and Nashville Railroad, half a mile east of Morris, and at a point midway between Fedora and Indio. It seems not unlikely that the clay deposit is coextensive with the flat ground along Turkey Creek, from Fedora to Indio, and along Cunningham Creek, for 2½ miles above its junction

with Turkey Creek, though it probably varies much in thickness and quality in this area.

This deposit of clay accumulated during the time that the creek waters were more or less ponded from some cause, for the clay is evidently composed of fine material that was washed down from the surrounding hills and slowly settled in still water. The cause of the ponding may have been a stratum of sandstone which crosses Turkey Creek near the bridge south of Morris and which retarded the down-cutting of the creek bed and acted as a dam to the water above.

The only underclay utilized in the Birmingham quadrangle is that under the Black Creek coal seam at Coaldale and vicinity. It is a gray plastic clay and makes a buff brick. It has been mined near the Southern Clay Company's brick works at Coaldale and at the Butterfly mine, about 1 mile east of Coaldale. At both points it is 4 feet thick. Its further extension is unknown to the writer, but there is evidently a considerable body of good clay in this locality. From both the places just mentioned the clay has been shipped to Birmingham and Bessemer for fire brick and terra cotta. It is now being mined at the Butterfly mine by the Sibley-Menge Press Brick Company for use in its new works 1 mile north of Coaldale. It is used for dry-press face brick of buff color, is mixed with shale for gray brick, and, with the addition of manganese, is used for speckled brick.

A bed of clay 4 to 6 feet thick underlies the Nickel Plate or American coal seam at Baileys Quarters, northeast of Brookside, where it is exposed in a cut of the North Alabama Railroad. The same clay also shows in a cut of this railroad at Clift station. Here there are three beds, two of which are each 2 feet thick and one 18 inches thick. A bed of clay 3 to 4 feet thick occurs at the same horizon at Short Creek, and clay of greater or less thickness has been noted under the same coal at other points in the region. It has not been utilized and nothing is known of its qualities.

A bed of very white, soft, plastic clay, 2½ feet thick, underlies the Pratt seam at the Thompson mine, northwest of Sayreton, but generally the coal seams of this region appear to be without underclays of economic importance.

SHALE.

The Alabama coal measures, reaching, in the deepest part of the Cahaba trough, nearly 7,000 feet in thickness, are made up of alternating shale and sandstone, the shale forming about two-thirds of the whole. Most of the shale is probably suitable for brick making. Shale from three different horizons in the Warrior basin and from one horizon in the Cahaba trough is now being utilized for brick. A project is afoot to use a lower Carboniferous shale for the same purpose also.

The highest bed of shale used for brick is that above the Mary Lee coal group in the Warrior basin. This is generally a blue clay shale, weathering yellow, about 200 feet thick. It is a persistent stratum, extending throughout the Warrior basin in this area where not removed by erosion. It is very uniform in appearance, though, as stated below, considerable variation in composition may occur at different points or at different levels. The vertical continuity of the shale is broken here and there by a layer of sandstone up to 10 feet thick or possibly more at some points.

Shale from the bottom of this mass is extensively used for brick by the Graves Shale Paving Brick Company, at Graves.

Below is a section of the shale quarry at this place:

Section of shale beds at Graves.

	Feet.
Yellow shale	6
Gray shale	10
Blue shale	28
	44

The shale dips from 10° to 15° W., into the hill. According to Ries,[a] the yellow shale is somewhat sandy and has a large content of ferric oxide. It vitrifies at 2,250° F. and fuses at 2,500°, yielding a brick that has a tensile strength of 40 pounds per square inch. The gray shale is less sandy and ferruginous. It vitrifies at 2,200° F. and fuses at 2,500°, yielding a brick of good red color, with an average tensile strength of 105 pounds per square inch. The brick are burned for nine days in round down-draft kilns. Paving brick and chemical brick are made. The latter are used principally for packing acid chambers in making sulphuric acid, a use for which they are well adapted, since, on account of their density, they absorb almost no water. The daily capacity is 50,000 brick and the actual output is reported to be 28,000 to 38,000 daily.

At Coaldale shale from two horizons is used. The upper horizon is that of the Jefferson coal seam and the lower is on an average about 150 feet below the Black Creek coal seam.

Shale from the upper horizon is utilized by the Southern Clay Manufacturing Company for vitrified paving brick.

The section at this company's quarry is as follows:

Section at Southern Clay Manufacturing Company's quarry, Coaldale.

	Feet.
Reddish, somewhat sandy shale	20
Dark clay shale with mica	15
Coal	1
Stiff gray, somewhat sandy shale	30
Coal	1

[a] Ries, Heinrich, Bull. Alabama Geol. Survey No. 6, 1900, p. 185.

The shale dips at a low degree to the east and, as it outcrops near the top of a hill, conditions for quarrying are very favorable. The 20 feet of reddish shale may differ from the underlying 15 feet of dark shale only in being more weathered. While the lower 30 feet of gray shale has been used, only that from the upper 35 feet is used at present in the proportion of two parts of red shale to one of dark. A test, apparently of the red shale, showed that vitrification takes place at 2,000° F. and viscosity at 2,150° F. The brick are burned in round down-draft kilns for nine days. They are red or brown. The capacity of this plant is 30,000 daily.

The shale lying 100 to 200 feet below the Black Creek seam is used for dry-press brick by the Sibley-Menge Press Brick Company, whose plant is about 1 mile north of Coaldale. The shale lies nearly flat and the bed is at least 70 feet thick, but only shale from the bottom 20 feet is used at present. In its weathered condition this is a gray clay shale, apparently with very little mica and sand. It makes a fine dry-press face brick of a pleasing red color. As stated on page 292, it is mixed with the underclay of the Black Creek coal seam for gray brick. The capacity of the plant is about 60,000 brick daily. No analyses of the shale nor physical tests of the brick have been made, so far as known to the writer, nor does he know whether the upper part of the shale bed is equally good for brick.

At Lovick, in the Cahaba coal field, shale lying between the Gould and Nunnally coal groups is being extensively worked at the brick plant of L. L. Stevenson. The whole bed utilized has the following section:

Section at Stevenson brick works, Lovick.

	Feet.
Reddish shale, probably weathered phase of gray shale below	10
Gray clay shale	18
Blue-black carbonaceous clay shale, with fossils	20

Shale from all these layers is mixed and used for pale-red common brick or brown vitrified brick. The time of firing is nine days, three days at low heat to expel the water and six days at red heat and finally at white heat. The capacity of the plant is 80,000 brick daily and the actual output is large. No analyses nor physical tests have been made.

The Lovick shale is traceable by its characteristic dark fossiliferous shale band for 6 miles southwest of Lovick. It is particularly well shown along the Leeds-Birmingham road in the southwest corner of sec. 28, T. 17 S., R. 1 W. It extends northeastward along the west side of Owens Mountain to Parsons station and beyond. At Lovick this shale dips 8° E., but both to the north and the south the dip reaches 20°.

A project is on foot to start brick works near Leeds, on the Southern Railway, using lower Carboniferous shale from the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 14, T. 17 S., R. 1 E. The composition of this shale, as shown by analysis, is such as to make it suitable for brick.

Not only at the points described above are the shales well adapted to brick making, but also at many other points on the same or other horizons throughout the area. It appears, therefore, that there are unlimited quantities of shale in this district from which high-grade paving and building brick can be made. At many points the conditions as regards quarrying the shale, cheap fuel supply, and transportation facilities are favorable for the location of brick works. The shale brick made in this region find an active market throughout the Southern States.

CLAY DEPOSITS OF THE WESTERN PART OF THE DURANGO-GALLUP COAL FIELD OF COLORADO AND NEW MEXICO.

By Millard K. Shaler and James H. Gardner.

INTRODUCTION.

The greater part of the area here considered lies in northwestern New Mexico, but a portion is included in southwestern Colorado.[a] In connection with reconnaissance work done in 1906 in this coal field, brief notes were taken regarding the occurrence and development of clay and shale deposits. As the region is but sparsely settled and at present lacks adequate railway facilities, the clay industry supplies only local demands and a small outside market. The total value of clay products marketed from this field in 1905 was about $75,000. The demand for clay and shale to be used in the manufacture of building material, tiles, conduits, etc., will naturally increase as the region develops and as better railway facilities become available. The occurrence of good coal in quantity in this region will do much to aid the development of a considerable clay industry.

At some places in the field limestones with which to mix the clay or shale in the manufacture of Portland cement occur near at hand, and some of them are of the proper composition for this use. The fire clays of the area so far tested contain a rather high percentage of fusible material, particularly iron oxide, but their adaptability for use in making semirefractory products and for lining copper converters has been shown at Durango and in copper smelters in Arizona.

CHARACTER OF THE CLAYS.

The clays of the area may conveniently be classified as clay shales, plastic clays, and fire clays.

The clay shales include in greater part the thick shale formations of the area—the Mancos and the Lewis—as well as many thinner beds intercalated with the sandstones and coal beds of the Mesaverde[b] and Laramie formations. All of these formations are of Upper Cretaceous age.

[a] For a more detailed location see report on the coal of this region by M. K. Shaler in a forthcoming bulletin of the Survey.

[b] For definition of the Mesaverde formation see description of the La Plata quadrangle, folio 60, U. S. Geol. Survey, p. 5, 1899.

The plastic clays include alluvial beds, adobe clays, certain unconsolidated Tertiary shales, and residual deposits derived from the weathering of clay shales.

The fire clays include deposits of a semirefractory nature, the beds of which now mined are interbedded with the sandstones, shales, and coals of the Mesaverde formation. Some of these are directly associated with the coal beds and are mined in connection with them.

COMMERCIAL DEVELOPMENT.

Durango-Mancos district.—The present development of the clay industry in the Durango-Mancos district, so far as known, is confined to the vicinity of Durango, Colo. The Durango Pressed Brick Company began operations as early as 1898, and in 1902 two plants were manufacturing bricks near Durango, but the company named is the only one now operating in the district. The plant is located on the Rio Grande Southern Railway 1 mile west of Durango. The shale used in making building brick is procured from the upper part of the Mancos, about 100 feet stratigraphically below the lowest coal bed of the Mesaverde formation. It is dark gray or black in color, hard, and at some places contains a little lime as a physical impurity. This lime is, however, generally present in concretionary form, and can be easily removed while the shale is being quarried. It is reported that nearby beds contain a higher percentage of lime than the bed quarried at this brick plant. The following analysis of the shale was made by P. H. Bates at the structural material laboratory of the United States Geological Survey at St. Louis.

Analysis of shale from quarry of Durango Pressed Brick Company.

Silica (SiO_2)	48.87
Alumina (Al_2O_3)	12.26
Ferric oxide (Fe_2O_3)	4.44
Manganese oxide (MnO)	.07
Lime (CaO)	10.06
Magnesia (MgO)	3.82
Sulphuric anhydride (SO_3)	.45
Alkalies: Na_2O	.55
Alkalies: K_2O	1.76
Water at 100° C.	1.27
Ignition loss, including carbon dioxide (Co_2)	16.39
	98.94

The color of the burned bricks is red. A dry-press Boyd machine is used in their manufacture. It is reported that the bricks shrink very little after sun drying.

The Durango Pressed Brick Company produces each year a small output of a semirefractory brick, which is generally used for boiler linings. In the manufacture of this class of brick the clay from a bed 2 to 5 feet in thickness, lying just below the coal bed above mentioned,

is mixed in proper proportion with the Mancos shale of the quarry. The color of this clay is dark blue. It is hard and is quite free from physical impurities. The bricks produced are white to buff in color.

Between the longitudes of Durango and Mancos the Mancos shale and some of the fire-clay beds in the coal-bearing Mesaverde formation occur in continuous outcrop. The Mancos also forms the basal part of Mesa Verde, a wide mesa lying just south of Mancos. Another shale bed, the Lewis, having a total thickness of about 1,600 feet and differing little in character from the Mancos, outcrops between the Mesaverde and Laramie formations in Rages Basin, southwest of Durango. Its exposure is continuous westward as far as La Plata River in the vicinity of Fort Lewis. Nowhere in this district, so far as known, has any part of this shale been worked for the manufacture of clay products; hence a practical test of its adaptability to such purposes is as yet entirely lacking. Judging from its physical characteristics, however, this shale bed doubtless is, in part at least, well adapted to the manufacture of ordinary brick.

With the exception of the San Juan and Gallup districts, yet to be discussed, this district is the only one in the field having at present the transportation facilities and markets necessary for any great development of the clay industry, and even this district is greatly handicapped by high freight rates and a consequent limited market. The market for the clay products of Durango outside of the local demand extends to Chama, N. Mex., on the east, and to Telluride and Silverton, Colo., on the north.

Vitrified brick has had, as yet, no market in this district; hence no attempt has been made to utilize the shales for the production of brick of this class.

At Rockwood, on the Denver and Rio Grande Railroad, about 16 miles north of Durango, limestone is quarried with which the shale of the Durango Pressed Brick Company's quarry might be mixed in the manufacture of Portland cement. An analysis of this limestone, made by P. H. Bates, at the structural material laboratory of the United States Geological Survey, follows:

Analysis of limestone from the Rockwood quarry.

Silica (SiO_2)	0.24
Alumina (Al_2O_3)	.13
Ferric oxide (Fe_2O_3)	.08
Manganese oxide (MnO)	.05
Lime (CaO)	55.87
Magnesia (MgO)	.19
Sulphuric anhydride (SO_3)	.10
Potash (K_2O)	.08
Water at 100° C	.07
Ignition loss (includes carbon dioxide)	43.47
	100.28

San Juan district.—The clay industry of the San Juan district is limited to Animas and San Juan valleys, New Mexico. In Animas Valley, at Farmington, a small brick plant has been in operation since 1900, and at Flora Vista and Aztec bricks have been manufactured since 1903. The production of this valley finds an outlet to Colorado markets over the branch line of the Denver and Rio Grande Railroad, which has recently been constructed down the valley from Durango. In 1903 a plant at Farmington successfully began the manufacture of what is known as "granite blocks," a building material manufactured largely from clay.

In San Juan Valley a production of building brick was reported from Fruitland by Biggs & Stephens in 1901. At Jewett and Shiprock building brick to supply a local demand were produced in 1903. At Shiprock the Government Indian School and Agency buildings were constructed during 1904 and 1905 of brick made on the ground from Mancos shale.

In both Animas and San Juan valleys, excepting in cases already noted, residual clays are used in the manufacture of brick. The product is common red building brick, and the market is local.

Gallup district.—The Gallup district centers about Gallup, N. Mex. The clay industry at Gallup and Clarkville, a coal-mining camp about 4 miles west of Gallup, consists almost wholly of the production of semirefractory fire clay, which is shipped to the copper smelters of southern Arizona, there to be used for the purpose of lining copper converters. Two companies at Gallup and one at Clarkville are now producing this semirefractory fire clay. At the Clark mine at Clarkville and at one place at Gallup the clay is worked in connection with coal mining. In the Rocky Cliff mine at Gallup the clay bed is from 10 to 20 feet thick and lies between two coal beds. After the lower coal bed is taken out the timbers are removed and the fire clay is allowed to fall; then the upper coal bed is mined. Two or three cars of this clay are shipped every day from this mine to southern Arizona.

Just south of the town limits of Gallup fire clay has been mined for five years by the Rocky Cliff Coal Mining Company. The bed varies in thickness from 7 to 11 feet. No timbering is necessary, as the bed is immediately overlain by a bed of massive sandstone. Until recently the production of this mine was rather large, two or three cars being shipped daily for use in Arizona smelters.

At Clarkville there are several beds of this semirefractory clay, varying in thickness from 1 to 20 feet. The beds lie comparatively flat and are of wide areal extent. About 12,000 tons of clay are produced annually at the Clark mine, and this production has been continuous since 1898. The clay is all shipped to the United Verde Copper Company, at Jerome, Ariz., where it is used for lining copper

converters in the smelting process, a use to which it is well adapted. An analysis of this clay is as follows:

Analysis of clay from the Clark mine, Clarkville, N. Mex.

Silica (SiO_2)	64.73
Iron oxide (FeO)	6.53
Aluminum oxide (Al_2O_3)	17.75
Volatile matter	5.09
Water	4.36

It will be noticed that the content of fusible material, principally iron oxide, is rather high for a fire clay, but the presence of this impurity does not seem to be detrimental to its use as converter-lining material. Many of the copper ores themselves contain a high percentage of iron, hence that present in the converter lining, if in rather small quantity, does not add greatly to the total percentage. It must be borne in mind, too, that the linings of copper converters are renewed before nearly every charge of ore, so that a lining of absolute refractory character is unnecessary. Quartzite is sometimes mixed with the clays used for this purpose, with the effect of greatly reducing the relative percentage of iron in the lining.

Besides this production, which in itself amounts to nearly 30,000 tons annually, valued on the cars at the quarries and mines at about $1.15 per ton, some building brick have been successfully made from the Mancos shale that outcrops in the "Hogback" 2 miles east of Gallup. The production of these brick has been limited by the local demand, and none have been produced for several years. As is shown by the following analysis made by Prof. Erasmus Haworth, of Kansas State University, this shale is not an exceptionally good brick shale, being rather high in lime. The presence of this, however, would not be detrimental if the shale were comparatively free from carbonaceous matter, but unfortunately its carbonaceous content is rather large, the ignition loss, probably in great part organic matter, being somewhat high.

Analysis of Mancos shale from Hogback east of Gallup.

SiO_2	56.29
$Fe_2O_3 + Al_2O_3$	23.18
CaO	3.73
MgO	2.91
Loss on ignition	11.53

It is possible that this shale bed or other beds in the overlying Mesaverde formation might be utilized, with some of the limestones occurring southeast and east of Gallup, in the manufacture of Portland cement. No analyses of these limestones have yet been made, however, so that a definite statement as to their quality is at present impossible.

The Carboniferous (Aubrey) limestone, which occurs near the railroad some distance east of Gallup, and also in the vicinity of Fort Wingate and Nutria southeast of Gallup, appears to be a limestone of very pure grade and might be used in connection with this shale in Portland cement manufacture. The abundance of coal at Gallup and in its vicinity, and the fact that no Portland cement plants are located near enough to this point to compete seriously with a plant established here are factors that might insure the success of such a plant.[a]

Other areas in the field.—The only areas within the field that could possibly, under present conditions of transportation, produce clay of any kind on a commercial basis have been discussed above. This limitation, however, is entirely dependent on present transportation facilities and market conditions and not on the absence of good clay and shale deposits.

South of Jewett the Mancos shale outcrops over a wide area west of the "Hogback" to the latitude of Crozier, where it disappears, dipping steeply eastward under flat-lying Tertiary sediments and lavas. At the southern limit of the Choiskai Mountains, east of Fort Defiance, Ariz., this formation reappears, dipping steeply in the same direction. From this point it trends southward, being crossed by the Santa Fe Railroad at Manuelito. From here the Mancos shale, flattening rapidly, courses southeastward, passing about 10 miles east of Zuñi village, thence southward to the latitude of Ojo Caliente, where its outcrop swings abruptly eastward for a few miles. From this point it courses northward, the rocks dipping steeply to the east through Ramah and Nutria and on beyond the horizon in the "Hogback" east of Gallup. Northeast of Gallup the strike, including that of the Mancos shale, again changes, in this case to the east, the shale occurring in continuous outcrop a few miles north of the Santa Fe Railroad until it passes beyond the limits of the area under discussion. Throughout its outcrop the shale at this horizon is characteristically the same, varying only in its thickness, which ranges from 750 feet to more than 2,000 feet.

South of Jewett the Lewis shale covers a rather limited area, finally occupying a thickness of only 150 feet on Rio Chaco east of Crozier. Its apparent quality, so far as concerns its uses considered in this paper, is the same throughout its occurrence.

Within the area outlined by the outcrop of the Mancos shale, outside of the three districts already discussed, many beds of shale and fire clay were noted at numerous places. These beds are of variable thickness and quality, but doubtless many of them have properties that fit them for use in the manufacture of clay products.

Within the limits of the field under discussion many clays of the varieties classed as plastic clays were noted. Among these is what is

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[a] Eckel, E. C., Bull. U. S. Geol. Survey No. 243, Pl. I.

commonly known as adobe clay, usually of residual origin, which is almost universally used by the Mexican inhabitants of the region in the manufacture of sun-dried brick to be used in constructing their buildings. In many places within the field timber is scarce or entirely absent, and building stone is not at hand. Consequently this adobe clay is of great value as a building material. The Indians of the Navaho Reservation use it to a large extent as a mortar and plaster in their stone huts. That the Aztecs successfully used this same material as a mortar in their cliff dwellings and other buildings is attested by its presence in the many ruins of these dwellings that are now scattered over the greater portion of the area. In many of the cliff-house ruins, at places well protected from the weather, this clay mortar is evidently as firm and coherent as when the houses were built, centuries ago.

KAOLINS AND FIRE CLAYS OF CENTRAL GEORGIA.[a]

By Otto Veatch.

INTRODUCTION.

Character.—Throughout the Cretaceous formations of central Georgia there are remarkable deposits of pure sedimentary kaolins and fire clays of great thickness. The occurrence of white clays throughout the fall-line region has been known for many years, but the quality and extent of the clays and their availability as the basis of large industries are being but slowly recognized. The valuable clays vary from the purest, soft, flour-like kaolin to the hardest, refractory, flint fire clay, and the beds range in thickness from 6 to 35 feet. The kaolins are suitable for use in the manufacture of porcelain, sanitary ware, encaustic tiling, etc., and the fire clays are suitable for high-grade fire brick and other fire-clay wares. On account of the sedimentary origin of the clays objection is frequently made to the application of the term kaolin to them. The clays, however, even in the unwashed state, more nearly approach kaolinite in composition than do many of the washed residual clays that are put on the market. The term kaolin is not generic and the objection has but little justification.

The only industries within the area that utilize these clays are two plants which manufacture fire brick and a small pottery which has been established recently at Augusta, Ga., for the manufacture of porcelain. Clay mining is carried on at a number of places, and the product is shipped to fire-brick and terra cotta manufacturers, to Ohio and New Jersey potteries, and to northern paper mills. About 25,000 tons are mined and shipped annually.

Location and extent.—The clay area is located in central Georgia along the fall line and extends in a northeast-southwest direction entirely across the State. The fall line is the contact between the ancient crystalline rocks of the Piedmont Plateau and the comparatively recent soft formations of the Coastal Plain. The streams of the

[a] Presented by permission of the State geologist of Georgia.

Atlantic Coastal region have falls at the points where they issue from the hard crystalline rock into the soft Coastal Plain formations, and a line connecting these points has therefore been called the fall line. The clays to be described are confined to a narrow belt of Cretaceous strata along the fall line and do not at any point extend more than 30 miles south of it. The eastern belt of clays, between Macon and Augusta, ranges in width only from 3 to 15 miles. Between Macon and Columbus the clays are also confined to a narrow strip, only a few miles wide. Just west of Macon, however, and near Fort Valley valuable clays are found throughout an area having a north-south width of about 30 miles.

GEOLOGY.

Formations containing clays.—As above stated the clays occur in strata of Cretaceous age. The Cretaceous deposits in Georgia lie in contact with the metamorphic and crystalline rocks of the Piedmont Plateau and extend entirely across the State. The greatest development of the Cretaceous is in west-central Georgia, between Ocmulgee and Chattahoochee rivers, where it aggregates, perhaps, 2,500 feet in thickness. East of Ocmulgee River and between Macon and Augusta only what is probably the lower part of the Cretaceous is exposed. It is confined to a narrow strip and is in many places overlapped by tongues of Eocene strata and obscured by superficial deposits of Lafayette and Columbia sands. The detailed stratigraphy of the Cretaceous in Georgia has not been worked out. It may, however, be divided into Lower Cretaceous (Tuscaloosa or Potomac) and Upper Cretaceous.

Tuscaloosa formation.—The Tuscaloosa formation, which contains the valuable clays of the State, probably occupies the same geologic position as the Potomac of Virginia and Maryland and as the Raritan of New Jersey, which contains the valuable clays of that State. It can be traced directly into the Tuscaloosa formation in Alabama, where it also contains valuable deposits of white clay. In South Carolina[a] the formation has been named Hamburg and has been subdivided into Lower Hamburg and Upper Hamburg. On account of the variable character of the formation in Georgia it will probably be difficult to subdivide and map the formation accurately. Recent field work done by the writer has made it possible roughly to subdivide that part of the formation lying between Macon and Augusta into a lower sand member and an upper clay member, which probably correspond to the Lower Hamburg and the Upper Hamburg of South Carolina, the upper member in both States containing the most valuable clays. For convenience of description the Tuscaloosa will be divided into an eastern belt and a western belt, Ocmulgee River forming the dividing line. The Tuscaloosa is composed chiefly of cross-

[a] Bull. South Carolina Geological Survey No. 1.

bedded quartz and mica sand, gravel, and white clay. The lower member of the eastern belt, or that part east of Macon and the Oemulgee River, consists of coarse, clayey gravel and sand, which near the contact with the crystalline rocks is locally an arkose and is at many places indurated. The clayey sand is generally cross bedded and has a characteristic pink color. It contains lenses of kaolin of remarkable purity, but most of these are of small extent, and the kaolin of which they are formed is likely to vary in texture or to grade into sand within a short distance. The upper member of the Tuscaloosa, in the eastern belt, is composed largely of clay in beds 10 to 35 feet thick, which is exposed at various places throughout a distance of approximately 90 miles. These clays vary from pure white and cream-colored gritless kaolins to semihard and flint fire clays. The clays of

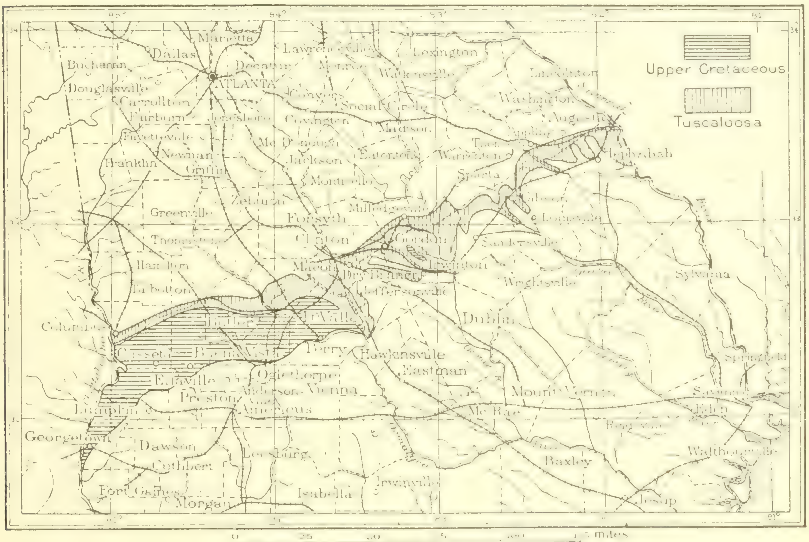

FIG. 10.—Map showing exposures of Cretaceous rocks in Georgia.

this formation are for the most part white or light colored, but in places may be mottled red, yellow, or purple by iron oxide. The formation is largely obscured by overlying deposits of Eocene sands and clays, exposures of clay occurring only where stream erosion has removed the overlying strata and in artificial cuts. The beds vary in thickness and are associated with more or less kaolinic sand. The thickness of the Tuscaloosa of eastern central Georgia varies from 50 to 500 feet.

The western belt of the Tuscaloosa, or that part lying between Macon and Columbus, is for the most part similar lithologically to the eastern belt. The subdivision of the eastern belt of the Tuscaloosa into an upper and lower member will probably not hold for that part

of the belt lying west of Macon. At its contact with the crystalline rocks, which are schist and gneisses, the formation in this region is composed of subangular quartz and feldspar gravel; farther south these are replaced by gray and pink micaceous sand containing irregular beds of kaolin and fire clay. The kaolin beds are not so thick here as in the eastern belt, and individual beds are not so extensive. No kaolins of great value have been discovered west of Butler. The Tuscaloosa in the vicinity of Geneva, near Columbus, differs in appearance from the formation as exposed in any other part of the State. Here it is composed largely of indurated material and consists of alternating layers of indurated clay and sandstone. The clay layers here are thin, dark colored, and iron stained. The Tuscaloosa in western Georgia is overlain by Upper Cretaceous strata, whereas in eastern Georgia it is overlain by sand and clays of Tertiary age. It is very difficult to distinguish the Tuscaloosa from the clayey sands of the Upper Cretaceous.

Upper Cretaceous.—The Upper Cretaceous strata in Georgia are exposed in a belt, 15 to 25 miles in width, which extends westward from Ocmulgee River to Chattahoochee River. No Upper Cretaceous strata are known to be exposed east of Ocmulgee River. The strata consist of unconsolidated sands and gravel, marls, clays, and limestone. The marls and limestone are best developed along Chattahoochee River, where the greatest thickness of strata is exposed. East of Chattahoochee River the formation is predominantly sand containing lenticular layers and irregular and nonpersistent beds of clay, although one of the marl beds can be traced from Chattahoochee River eastward to a point 4 miles east of Marshallville, in Houston County. The sands are ferriferous and contain thin layers and hollow nodules of siliceous limonite. At some localities, however, there are great thicknesses of pure white, extremely fine, loose sand. No clays that are likely to be of value have been discovered in the formation except in Houston County, where white clays occur in great quantity.

DESCRIPTIONS OF CLAY DEPOSITS BY LOCALITIES.

The following descriptions do not by any means include all the localities where good clays are exposed. The aim is to describe the clay at the principal localities, in order to give some idea of its extent, quality, and accessibility.

DRY BRANCH.

Dry Branch is on the Macon, Dublin and Savannah Railroad, 9 miles southeast of Macon. Here the most extensive and purest beds of clay occur and here clay mining is most actively carried on. The clay mined is largely a soft kaolin, suitable for the paper and pottery trade. Four companies are at present engaged in active mining,

the Atlanta Mining and Clay Company, the Georgia Kaolin Company, the American Clay Company, and I. Mandle & Co.

At the pits of the Atlanta Mining and Clay Company, 2 miles southeast of Dry Branch station, the clay bed is in places 25 feet thick and is composed for the most part of a plastic, soft, pure kaolin. Only 8 to 15 feet of clay, however, is worked. This clay is so pure that it is dried and shipped in the crude state, without preliminary washing. The clay has an overburden of nonindurated Tertiary sand and clay, the thickness of which increases gradually from 10 feet to a maximum of 100 feet. The clay bed as it appears in the pits is massive and jointed and is not laminated, but occurs in one solid bed. It is white to cream colored, but shows slight staining of iron and manganese along the joint planes and contains some small, yellow pseudo-iron nodules. Mining is carried on in open pits, the overburden being removed by a steam shovel. The following section shows the nature of the overburden:

Strata overlying clay bed at pits of Atlanta Mining and Clay Company, near Dry Branch, Ga.

	Feet.
1. Red sand	3
2. Greenish, laminated, tough clay	4
3. Very fine red sand	5
4. Green clay layer	1
5. Fine red micaceous sand, containing smutty particles of a manganese mineral	4
6. Yellow ocherous sand	3
7. Sand containing white clay pebbles	3
8. Kaolinic sand	8
9. White kaolin	12

The following analysis of the No. 1 paper and pottery kaolin shows the purity of the product in its crude state:

Analysis of kaolin from pits of the Atlanta Mining and Clay Company.

[E. Everhart, analyst.]

Moisture at 100° C	10.72
Loss on ignition	12.39
Silica	40.28
Alumina	34.72
Ferric oxide	.84
Manganous oxide	Trace
Lime	.05
Magnesia	.04
Sodium oxide	Trace
Potassium oxide	Trace
Titanium dioxide	1.15
Sulphur	.00
Phosphorus pentoxide	.00
	100.19

The kaolin contains

Feldspar	Trace	Sand	1.570
Quartz	1.570		
Mica	Trace		
Ferric oxide			.745
Clay substance			97.685
			100.000

At the pit of the American Clay Company, 1½ miles southeast of Dry Branch, the clay is in one massive bed 18 feet thick. It is soft drab to cream color and yellow, jointed, and very free from "grit" or mechanical impurities. It is overlain by 20 to 30 feet of red, yellow, and gray sand, which near the pit increases to a maximum of 80 feet. The clay is shipped without washing and is used entirely as a filler in the manufacture of paper. When dried it whitens in color, and when pulverized has the feel and color of low-grade wheat flour.

The Georgia Kaolin Company operates a mine 2 miles east of Dry Branch. The bed is 18 feet thick. The upper 5 or 6 feet of the bed is hard and contains manganese stains and small curious fingers of sand. The lower part of the bed is soft, plastic, gray or cream colored, and remarkably free from grit. A rational analysis shows no quartz sand and only a very small percentage of mica. The clay is suitable for pottery and paper uses. The following is an analysis of the purer clay found here:

Analysis of kaolin from pit of the Georgia Kaolin Company.

[E. Everhart, analyst.]

Moisture at 100° C	1.22
Loss on ignition	13.16
Silica	44.76
Alumina	38.41
Ferric oxide	.63
Lime	.20
Magnesia	.09
Sodium oxide	.09
Potassium oxide	.35
Titanium dioxide	1.37
Sulphur	None
Phosphorus pentoxide	None
	100.58

The composition of the kaolin is—

Feldspar	0.680	Sand	5.189
Quartz	None		
Mica	4.509		
Ferric oxide			.479
Clay substance			94.332
			100.000

Physical tests[a] show that the clay requires 21 per cent of water to develop a plastic mass, and that when made into air-dried briquettes it has a tensile strength of 50 to 55 pounds per square inch, and air shrinkage of 5 per cent. The clay when burned to cone 8, or about 2,354° F., was pure white, without trace of a yellowish tint. At 3,100° F. the material showed no signs of fusing.

At the pit of I. Mandle & Co., 2 miles south of Dry Branch, only 10 feet of white clay is exposed, but the bed is probably somewhat thicker and is of large extent areally. The clay here is white, semihard, and very free from quartz grains. It is too hard for a No. 1 paper clay, but is very pure and is sold crude and in bulk almost entirely for pottery use.

The clay beds at the above four localities are in the same geological position, namely, at the top of the Tuscaloosa, and in contact with Eocene sand and clay. They are parts of one persistent clay formation that ranges in thickness from 10 to 35 feet. The strata in this region are nearly horizontal, having only a very slight dip southward. The amount of overburden of the clay beds may be estimated from surface levels.

MCINTYRE AND GORDON.

In the vicinity of McIntyre and Gordon, on the Central of Georgia Railway, 22 and 30 miles, respectively, east of Macon, there are extensive beds of fire clays and some pottery kaolins. The fire clays lie at the base of Tertiary ridges and are exposed wherever the small streams have cut through the Tertiary clays and sands that form the surface rock. The clays are usually white in color and range in hardness from soft, semihard and "punky" to very hard. They are both plastic and nonplastic and show fusing points ranging from Seger cones 28 to 36 (3074° F. to 3362° F.). The soft clays contain more iron than the Dry Branch kaolins and are in places mottled red, yellow, and purple by iron oxide. Some of the fire clays are very hard and consist of about equal parts of quartz sand and kaolin, the kaolin forming the cementing material. Throughout this region there are peculiar "punky," white, pitted clays, which have the property of hardening slightly upon exposure. This clay is sawed from quarries and used locally for building chimneys and foundations. It possesses little or no plasticity, but is highly refractory and would be especially useful when finely ground for making fire brick. The clay beds of this region vary in thickness from 10 to 30 feet and are entirely undeveloped.

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[a] Tests made by H. Ries for the Georgia Kaolin Company.

The following are some chemical and physical tests made upon clays in this vicinity:

Chemical and physical tests of clays from beds near McIntyre and Gordon, Ga.

	1.	2.	3.	4.	5.	6.
Moisture at 100° C	0.89	0.90	....	0.21	....	....
Loss on ignition	14.10	13.47	....	14.52	....	....
Silica, total	43,57	44.22	....	43.61	....	....
Alumina	39.34	38.40	....	40.42	....	....
Ferric oxide	.72	1.70	....	.70	....	....
Lime	None.	Trace.	....	.37	....	....
Magnesia	.10	Trace.	....	None.	....	....
Soda	.05	Trace.	....	.83	....	....
Potash	.10	.28	....	Trace.	....	....
Titanium dioxide	1.61	1.48	....	....	....	....
Common fluxing impurities	.97	1.98	....	1.90	....	....
Fusing point, Cone	(a)	....	36	36	35	36

[a] Unaffected at 3000° F.

1. Semihard fire clay, used locally as a building stone, 3 miles east of McIntyre; E. Everhart, analyst.
2. Same locality as above, iron-stained soft kaolin, 4 to 15 feet thick; E. Everhart, analyst.
3. White friable clay, 1½ miles south of Gordon; clay bed 12+ feet thick.
4. Cream-colored, fine-grained hard clay, 3 miles south of Gordon; clay bed 30 feet thick.
5. Clay from bed 1½ miles east of Lewiston.
6. Clay from bed 1 mile south of Irwinton. A very pure clay, but cracks when burned.

GIBSON.

Gibson is on the Augusta Southern Railroad, 50 miles southwest of Augusta. Large undeveloped deposits of both kaolin and fire clay occur here. The clays are in the same geologic position as the clays farther southwest—in contact with Tertiary strata and at the base of Tertiary ridges and hills. They are overlain by loose sand, green and drab clays, and occasionally by thin beds of limestone. Three miles east of Gibson there is a kaolin deposit that varies in thickness from 18 to 30 feet and has an average thickness, as determined by auger borings, of 23 feet. This bed is, for the most part, white, but contains some cream-colored and light-yellow streaks and varies considerably in its content of quartz and mica. The kaolin on the greater part of the bed could be profitably washed. Analysis shows that even in the crude state it is one of the purest kaolins found in the State. It is remarkably plastic but has low tensile strength. It burns to a dense white body at Seger cone 9 (2390° F.), the temperature usually attained in burning white ware. Small amounts of this clay are being used for porcelain ware in the pottery at Augusta. The following analysis shows the purity of the clay:

Analysis of kaolin from Gibson, Ga.

[E. Everhart, analyst.]

Moisture at 100° C	0.44
Loss on ignition	11.83
Silica	47.37
Alumina	38.06
Ferric oxide	.63

Lime	Trace.
Magnesia	Trace.
Sodium oxide	.60
Potassium oxide	.26
Titanium dioxide	1.37
Sulphur	.04
Phosphorus pentoxide	Trace.
	100.60

The kaolin contains—

Sand	8.609
Ferric oxide	.035
Clay substance	91.356
	100.000

The following geological section was made along a sloping ridge at the point where this kaolin outcrops:

Section along ridge 3 miles east of Gibson, Ga.

	Feet.
1. Red, cross-bedded sand capping the ridge	30
2. Drab and green colored soft calcareous clay; contains Eocene fossils	20
3. Thin-bedded, soft, fossiliferous limestone	5
4. Calcareous clay and sand	5
5. Kaolinic quartz sand; contains large pellets of white clay and disseminated kaolin; belongs to the Tuscaloosa formation	15
6. Kaolin, stained with iron oxide near the top	6+

Two miles east of Gibson there is a bed of flint fire clay 20 feet in thickness. This is a cream-colored clay, with yellow iron stains, containing 18 per cent of quartz sand and only 1.42 per cent of fluxing impurities. It is the hardest clay found in central Georgia, having a hardness of 2.5 to 3. It breaks with a conchoidal and splintery fracture and disintegrates very slowly on exposure to the weather. No plasticity is developed even by fine grinding. It is very refractory and with a plastic clay for a bond will make excellent fire brick.

HEPHZIBAH.

The Albion Kaolin Company is mining kaolin at Hephzibah. The kaolin here is 12 feet thick, soft, free from grit, and plastic. It is in one massive jointed bed, overlain by about 20 feet of indurated and nonindurated sand and gravel, which gradually increases in thickness away from the bed. The kaolin, on account of its freedom from grit and its softness, is an excellent paper clay, and the product of the mine is shipped to northern paper mills. The clay, however, is also adapted to the manufacture of pottery. The following analysis of the crude clay represents its average quality.

Analysis of kaolin from Hephzibah, Ga.

[E. Everhart, analyst.]

Moisture at 100° C	0.55
Loss on ignition	12.42
Silica	44.99
Alumina	38.59
Ferric oxide	2.11
Lime	Trace.
Magnesia	.05
Soda	.24
Potash	.11
Titanium dioxide	1.04
Phosphorus pentoxide	.13
Sulphur	.02
	100.25

The kaolin contains—

Feldspar, Quartz, Mica	Sand	3.61
Ferric oxide		1.90
Clay substance		94.49
		100.00

PERRY, HOUSTON COUNTY.

A fine deposit of kaolin is exposed in Upper Cretaceous strata on Bay Creek, 2 miles northwest of Perry, at various points along the base of a ridge. A shaft has been sunk into the kaolin 15 feet, and it is reported that the bed has been penetrated to a depth of 20 feet by auger boring. Within an area of 500 acres many prospect holes and wells have been put down, most of them encountering kaolin. The clay evidently occurs in great quantity, but is likely to vary in thickness. The overburden consists of very fine, variegated, micaceous sands, having a maximum thickness of 80 feet. The top of the bed, near its contact with the overlying ferriferous sands, is stained red and yellow by iron oxide. The clay is chalky white when dry and contains only a very small percentage of sand. It is probably best adapted for use in the manufacture of white ware. An analysis follows:

Analysis of kaolin from Perry, Ga.

[E. Everhart, analyst.]

Moisture at 100° C	1.47
Loss on ignition	13.58
Silica	44.86
Alumina	37.34
Ferric oxide	.56
Lime	Trace.
Magnesia	.05
Soda	.04
Potash	.22
Titanium dioxide	1.66
	99.78

The kaolin contains—

Feldspar..	} Sand	2.60
Quartz....		
Mica		
Ferric oxide		.32
Clay substance		97.08
		100.00

BUTLER.

At Butler white clays occur in considerable quantity and have been mined at one locality. The clay is located in the western belt of the Tuscaloosa and is typical of the clays of this belt. A clay mine was operated for a few years at a point 2½ miles west of Butler, but operations there have been suspended since 1905. The clay bed mined has a maximum thickness of 20 feet and is in part sandy, but much the greater portion of it could be utilized by washing. The clay in this vicinity occurs in lenticular layers, which vary greatly in thickness within short distances. The kaolin varies in texture and may grade rapidly from pure clay into a micaceous sand. It is gray or cream colored, becoming white when dry and is soft and plastic, but coarse particles of quartz are scattered throughout its mass. The overburden consists of sand and is much thinner than in most localities. It reaches a maximum of 20 feet.

The clay was run through an air separator and shipped largely as a filler for wall paper. A small amount was also shipped to the cotton mills at Columbus, Ga., where it was used for sizing cotton cloth.

A sample of this clay was analyzed after it had been run through a pulverizer and air separator.

Analysis of kaolin from Butler, Ga.

[E. Everhart, analyst.]

Moisture at 100° C	0.65
Loss on ignition	13.26
Silica	47.03
Alumina	37.37
Ferric oxide	1.15
Lime	Trace.
Magnesia	.06
Sodium oxide	.17
Potassium oxide	.18
Titanium dioxide	.17
	100.04

The analysis shows that the clay contains—

Feldspar......	0.676	} Sand	4.186
Quartz........	1.490		
Mica..........	2.020		
Ferric oxide			1.074
Clay substance			94.740
			100.000

In the following table of analyses and tests the kaolins of Georgia are compared with the best known domestic and foreign kaolins. The Georgia, South Carolina, and Florida clays are sedimentary in origin; the remaining five are residual clays.

Table showing composition and comparative tests of clays.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Silica	47.37	44.76	45.39	45.02	45.70	46.24	46.87	48.26	47.50
Alumina	38.06	38.41	39.19	38.98	40.61	36.25	38.00	37.64	37.40
Ferric oxide	.63	.63	.45	.77	1.39	1.64	.89	.46	.80
Lime	Trace.	.20	.51	.03	.45	.19	Trace.	.06	Trace
Magnesia	Trace.	.09	.29	.07	.09	.32	.35	Trace.	......
Potash	.26	.35	.83	.26	2.82	2.53	1.22	1.56	1.10
Soda	.60	.09		.55					
Titanium	1.37	1.37	......	.85	......	......	......	......	......
Water	[a] 11.83	13.46	14.01	13.58	8.98	13.53	12.70	12.02	12.48
Moisture	.44	1.22	......	......	.35	......	......	......	......
Fluxes	1.49	1.36	2.08	1.68	4.75	4.70	2.46	2.08	1.90
Fusion	......	3,100 °F.+	......	......	2,700° F.+	......	......	......	[b] 27+
Color burned	White	White.	Nearly white.	White.	white.	......	......	......	......
Tensile strength	Low.	50 to 55	65	13	20	......	......	......	......
Air shrinkage	10%	5%	15%	10%	6%	......	......	......	......
Fire shrinkage		15%			4%	......	......	......	......
Clay substance	91.33	94.33	......	96.95	96.81	......	......	......	99.00

[a] Contains 0.04 per cent sulphur.

[b] Cone.

1. Kaolin from Gibson, Ga., unwashed.
2. Kaolin from Dry Branch, Ga., unwashed.
3. Ball clay from Edgar, Fla., washed.
4. Kaolin from Aiken, S. C., unwashed.
5. Kaolin from Webster, N. C., washed.
6. Kaolin from Brandywine Summit, Pa., washed.
7. Zettlitz, Bohemia, washed.
8. Cornwall, England, washed.
9. West Cornwall, Conn., washed.

CLAY MINING.

Clay mining is carried on actively at two localities, Dry Branch and Hephzibah, and small amounts of clay are mined at Griswoldville, Lewiston, and Carrs Station. No washing plants are installed at any of these places, the clay being shipped in the crude state. At Dry branch and Hephzibah the kaolin is placed in long drying sheds, and after about three weeks of air drying is ground into flour or into small lumps, and is shipped in sacks, each holding about 200 pounds, and in wooden casks each holding approximately a long ton. The overburden is removed by hand labor and by steam shovels, and mining is done by the open-pit method. Both the overburden and the clay are soft, and no blasting is required. The installation of washing plants and steam shovels will materially increase the profits in mining these clays, for a product of greater purity and uniformity can thereby be procured, all the material that now forms waste can be utilized, and larger quantities of clay can be handled. The enormous profits that may accrue from some other forms of mining are not to be expected in clay mining; but by properly handling the clay and by economical management a reasonable profit on an investment can be obtained.

CLAY RESOURCES OF THE ST. LOUIS DISTRICT, MISSOURI.

By N. M. FENNEMAN.

In the year 1905 St. Louis produced and sold about $5,000,000 worth of clay products, this being about one-thirtieth of the entire output of the United States. The products here counted comprise

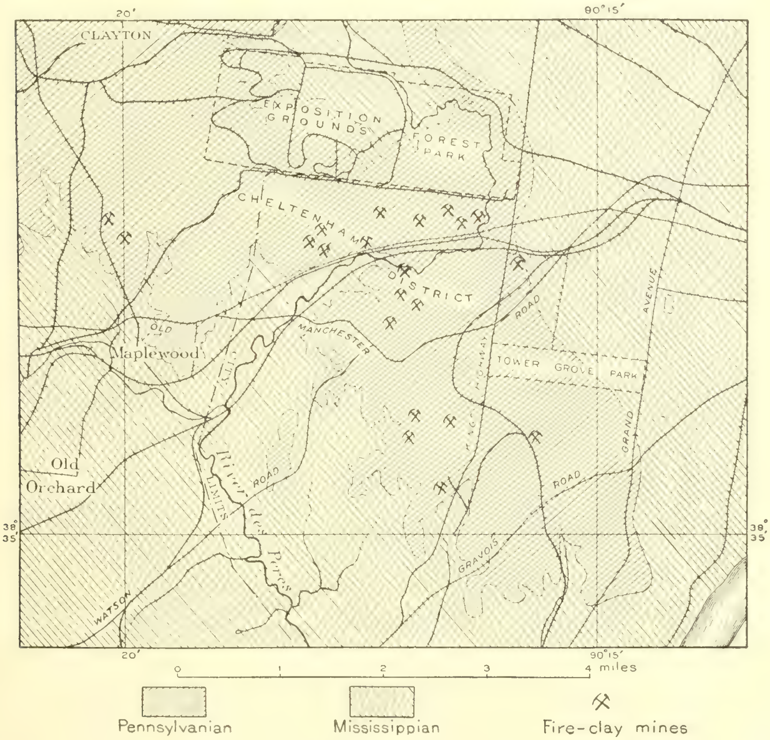

FIG. 11.—Map of Cheltenham district and vicinity, St. Louis.

those of fire clays, shales, and brick clays. Inasmuch as a very large proportion of the total consisted of fire-clay products, and these were derived in large part from a single section within the city limits, it may be seen that St. Louis is one of the most important centers of the clay industry.

FIRE CLAYS.

CLAYS AT CHELTENHAM.

The area from which fire clays are derived has its center in a section of the city known as Cheltenham, lying south of Forest Park. It extends about 4 miles southeastward, in a tongue about 2 miles wide, and westward to a line running south from Clayton. An examination of the geological map (fig. 11) will show that this area is an extension or peninsula of the Pennsylvanian coal measures. The clay is mined very much after the manner of coal mining, both shafts and slopes being used. The depth below the surface is generally between 60 and 100 feet.

STRUCTURE AND DISTRIBUTION.

The geologic feature to which the presence of the fire clay within the area named is mainly due is a faint synclinal basin, whose center is not far from the southeast corner of Forest Park. North and east of this point there are no mines. Certain small variations from the general structure here described are probably due to minor folds, which are too small to be reduced to system with any data now obtainable. The lowest level from which the clay is mined is 404 feet above sea level, this being within the bend of the Des Peres River, near the southeast corner of Forest Park. From this point the elevation of the bed increases both to the west and to the south. The highest known level of the clay is 494 feet, in the Van Cleave mine, about 1 mile northwest of the insane asylum, near the intersection of the old Manchester and Watson roads. West of that point the strata are affected by a gentle anticline, over which the Des Peres River flows southwestward, the combined effects of the folding and erosion being to erode the clays from this area. Similar conditions on the east and south of the productive area have caused the complete erosion of the clay-bearing series.

In so far as system is discernible in the gentle folding, all axes seem to have a northwest-southeast direction. The productive area south of Clayton lies in a gentle syncline parallel to the one above mentioned, the two axes being 4 or 5 miles apart.

STRATIGRAPHY.

Within the area named, the Pennsylvanian coal measures lie unconformably on the St. Louis limestone of the lower Carboniferous. These coal measures are generally less than 100 feet thick. It is not probable that the beds here present represent the base of the system. They consist mainly of shales and clays, but comprise subordinate beds of limestone. At the base is a thin though persistent sandstone forming the floor of the fire clay mines, all of which are in the very persistent overlying bed of fire clay known as the "Cheltenham seam."

The same gentle downward folding that has resulted in the preservation of the fire clays from erosion has preserved a few thin beds of coal. One of these, which is of small areal extent and has a maximum thickness (in this part of the field) of perhaps $1\frac{1}{2}$ feet, lies immediately above the fire clay. Another, equally small, with a maximum thickness of 4 to 6 feet, lies 40 to 50 feet higher. The early history of the city shows that both of these were once mined, and although their content was such as would now be considered insignificant, their influence on the early development of St. Louis industries was great. They are not now mined, except incidentally, in mining the clay.

SECTIONS.

The details of sections showing the beds passed through in sinking shafts would be of little value because of the local character of some of them and the variation in the thickness of all. A comparison of many sections, however, shows certain more or less constant features as follows:

Generalized section of coal measures.

	Ft.	in.
1. Soil, loess, and clays of variable thickness.		
2. Weathered limestone ("tumble rock")	0 – 4	0
3. Pipeclay, etc.—maximum	0 –15	0
4. Coal (local)	0 – 6	0
5. Limestone or "very hard blue rock," often blasted with dynamite	3 –15	0
6. Red and blue clays, "keel," pipeclay, etc	13 –36	0
7. Coal (very local)	0 – 1	6
8. "Roof," consisting of dark shaly sandstone or arenaceous shale, often preserving "weeds"	1 – 7	0
9. "Clod," an impure clay, liable to fall down (local)	0 –	8
10. Coal streak (very local)	0 –	3
11. Fire clay—Cheltenham seam	$2\frac{1}{2}$–12	0
12. Light-colored sandstone with pyrite crystals and ferruginous nodules, commonly forming the "floor"	1 – 9	0
13. Limestone containing red cherts.		

As illustrations, the actual sections of two shafts are given below:

Section at Jamieson-French mine, $1\frac{1}{2}$ miles south of Clayton.

	Ft.	in.
Loess and soil	15	0
Red clay	10	0
"Gravel"	1	0
Limestone fragments in clay	3	0
Gray pipeclay	15	0
Very hard limestone	6	0
Red shale	10	0
Soft black shale	3	0
Coal	0	8
Black sandy shale	1	6
Fire clay—Cheltenham seam; good clay taken out	8	6
Depth to floor	73	8

Beneath the good fire clay are several feet of green or iron-stained clay not mined. Beneath this is pyritiferous sandstone of unknown thickness, probably at least 6 feet. At an outcrop one-half mile to the south this sandstone is underlain by limestone containing large red cherts.

Section at Krümmel and Büchner mine, Columbia avenue and Woods street.

	Ft.	in.
Soil, loess, etc	38	0
Limestone	4	0
Coal	2	6
Very hard "blue rock"	8	0
Clay, not refractory	10	0
Blue shale and "keel"	15	0
Dark shaly sandstone "roof"	2	6
Fire clay, Cheltenham seam	7	0
Light pyritiferous sand floor.		
Depth to floor	87	0

THICKNESS OF FIRE CLAY.

The thickness of the main or Cheltenham seam may vary from 1 to 12 feet within a small fraction of a mile; it rarely if ever pinches out entirely. Most of the mining is done where the thickness ranges from 3 to 8 feet; where it exceeds that amount, as at the northeast corner of Cheltenham, the mining is generally limited to about 8 feet from the best part of the seam. Near the center of the area, which is near the Laclede mine or within 1 mile to the south of it, the seam generally ranges about 7 feet in thickness, all of this being good clay and taken out. The seam is mined at places where it is only 2½ feet thick. The common belief is that where the seam outcrops it is increased in thickness by weathering. Along the Des Peres River through Cheltenham its thickness is perhaps 1 foot, being from 12 to 15 per cent of the original thickness.

ROOF.

The variable thickness and changeable character of most of the beds above the clay are unimportant, but the character of the roof is a matter of much concern. Bed No. 8 in the above general section is the bed which in all mines supports the overburden and under which all posts must be set. This rock is generally sufficiently strong to span all entries and rooms, but breaks off short and falls, allowing the overburden to fall in behind the line of supporting posts when the pillars have been mined out. The mining is planned with this fact in view. The roof is more apt to be too strong than too weak. In that case it fails to break short just behind the row of posts, but sinks down over a large area, squeezing the unmined clay and probably breaking the posts.

FLOOR.

The floor of the mine is generally the light-colored pyritiferous sand, No. 12, above. Locally the pyrite is oxidized and the sand is yellow. At some places, especially where the clay seam is very thick, its basal portion is sandy and abounds in pyrite, and is poorly distinguished from the underlying bed. At places, as in the Christy mine and the Evans and Howard No. 11, this basal clay is green and very sandy, locally oxidized to yellow and brown colors. At the latter mine and at the Parker and Russell mine, west of Kingshighway, this basal clayey mass contains large red cherts, which elsewhere (as at the Laclede, Christy, and Jamieson-French mines) are found only in the underlying limestone.

This limestone is reached in a few of the mines in digging sumps, into which the mine is drained and from which the water is pumped. On account of the imperviousness of the overlying beds, most mines are practically dry until the pillars have been drawn from some portion, thus allowing settling and cracking of the higher beds.

INTERRUPTIONS OF THE CLAY SEAM.

The surface of the floor is locally affected by gentle ridges or rolls that rise from a few inches to 1 or 2 feet in a width of a few yards. One such ridge in the floor of the Jamieson-French mine reaches the roof, cutting out the clay entirely. It is known as a "whaleback." Its trend is northwest-southeast.

In several mines the roof thickens, at some places its surface being depressed almost or quite to the floor, as in the Hume mine, south of the Insane Asylum, where a band about 200 feet wide trending northeast-southwest is thus affected. In this mine, as in a group of mines near the southeast corner of Forest Park, the lower surface of the "horse" is longitudinally grooved or fluted on a large scale.

GRADES OF CLAY.

The clay seam is rarely of uniform quality throughout its thickness. Its usual variations are due to varying proportions of silica and carbonaceous matter and to the presence or absence of pyrite and other forms of iron. In the western part of the field pyrite, the chief impurity, is found mainly in the upper part of the seam. The lower clay is of the highest grade. It is probable, however, that several feet remaining as floor are equivalent to the basal portion of the clay bed in Cheltenham. In that district it is common to regard the middle of the seam as best, the top being liable to contain carbonaceous matter and the basal portion being siliceous. In the southern part of the field it is customary to speak of the clay as upper and lower, the former being of the highest grade, the latter being lighter colored and more siliceous.

USES.

The choicest of the clay is sold for glasshouse use. At several of the mines the clay is assorted, that which is freest from impurities being sold in the raw condition for glass pots. Good clay which contains a small amount of impurity is washed and then sold for the same purpose. For brick it is not necessary that the clay be so pure. Much of the fire clay mined in Cheltenham is used without assorting for ornamental and facing bricks or is mixed with various other clays to make sewer pipe.

FIRE CLAY IN OTHER LOCALITIES.

About 9 miles northwest of Cheltenham and 3 miles east of Creve Cœur Lake the St. Louis Vitrified and Fire Brick Company operates a mine and factory. The base of the fire clay bed at this point is nearly 90 feet below the upland level. The thickness of the clay is 12 to 15 feet, 12 feet of good clay being mined. It is practically certain that this clay is at the same horizon as that mined in the city of St. Louis. This mine is within one-half mile of the western outcropping edge of the coal measures. Beneath the clay is a sandstone with ferruginous nodules; above are 6 inches of slate overlain by 18 inches of coal. Above that are 55 feet of soft shales, mostly of a red color. Essentially the same section was noted in drilling at the St. Louis Clay Burning Company's plant, one-half mile to the southeast. At this place, it is said, limestone was encountered beneath the clay. There is also a fire clay mine at Malcolm station, southeast of Creve Cœur Lake. The section there is the same, including the 18-inch coal seam.

Fire clay has long been known north of Baden, a northern suburb of St. Louis. At the shale quarry of the St. Louis Portland Cement Company the massive shales, which are mined, are underlain by from 2 to 3 feet of black shale and this by 1½ feet of coal, beneath which is the fire clay.

In view of the wide separation of the points at which the Cheltenham fire clay seam is mined, it is quite probable that it may be found at many places where no prospecting has yet been done.

SHALES.

A characteristic feature of the coal measures near St. Louis is its very large proportion of plastic shales. These are largely used in the manufacture of vitrified paving brick, both in St. Louis and at points farther northwest, near Creve Cœur Lake. This shale is that which appears in the sections above the fire clay, but west and north of the city it occurs in thicker and more continuous beds, of uniform quality. At Castello and Malcolm stations almost the entire 40 to 55 feet intervening between the loess and the coal seam overlying

the fire clay consists of workable shale, generally of a red or brown color, but with some blue shale at its base.

Similar clays from a place 4 miles northwest of Glencoe, a station on the Missouri Pacific Railroad, about 20 miles west of St. Louis, are largely used in St. Louis in the manufacture of terra cotta and sewer pipe, though shales from this vicinity have also been used extensively for brick. Yellow and blue shales that occupy the same stratigraphic position are extensively mined at Prospect Hill, a few miles north of St. Louis, and used in the manufacture of Portland cement, being mixed for that purpose with the St. Louis limestone.

RED BRICK.

Many yards in and around St. Louis are making red brick from the loess, which is commonly called "yellow clay." This is rarely less than 10 to 15 feet thick, and near the bluffs may be three or four times that thick. It differs in texture at different depths, the upper portion being "stronger," more clay-like, and less mealy than the main body. Partly to obtain a thorough mixture of these different grades and partly to allow some weeks or months of "sweating," thus reducing all lumps, large quantities of the loess are commonly brought in from the pits and kept under shed for some time before using. A good grade of red brick is made, and the supply of good loess here and elsewhere is limitless.

WHITE CLAYS OF SOUTH MOUNTAIN, PENNSYLVANIA.

By George W. Stose.

INTRODUCTION.

The deposits here described are very siliceous clays that are associated with the wash and decomposition products of certain Cambrian strata of South Mountain. They have been actively mined in the vicinity of Mount Holly Springs, Pa., 6 miles south of Carlisle, where they are of unusual thickness and purity. These deposits have been previously described by T. C. Hopkins in an exhaustive report on the clays and clay industries of Pennsylvania,[a] from which some of the data in this paper are taken. Several new mines have been opened since that report was prepared, and the mine and plant of the Philadelphia Clay Company, which is the largest mine in the region and was formerly closed to visitors, was thoroughly inspected by the writer.

TOPOGRAPHY AND GEOLOGY.

South Mountain forms a rude arc of a circle curving from Potomac River at Weverton north and east to Susquehanna River south of Harrisburg. It is composed of several parallel ridges and intervening steep-sided longitudinal valleys. The larger part of the drainage of the mountain area passes westward through rugged water gaps into the Cumberland Valley, a low rolling limestone valley 10 to 15 miles wide, part of the great Appalachian Valley that extends from northern Pennsylvania to central Alabama.

The mountain ridges are composed largely of hard sandstone or quartzite and the longitudinal valleys of interbedded shale. These rocks are of Georgian (Lower Cambrian) age, fossils of that age having been found by C. D. Walcott[b] in their uppermost beds—the Antietam sandstone. They form an anticlinorium, with vertical or overturned dips on the northwest side. In the core of this anticline pre-

[a] Ann. Rept. Pennsylvania State College for 1899-1900, appendix, offic. doc. No. 21.

[b] Bull. U. S. Geol. Survey No. 134, p. 24.

Cambrian altered basic and acidic lavas are exposed. The Cumberland Valley is composed of Cambro-Ordovician limestones, which in the eastern part of the valley are interstratified with shales and siliceous beds, and in the western part are overlain by Utica and Eden shales. All of the rocks are closely folded, at many places overturned, and here and there faulted; and a southeast cleavage is strongly developed in the shales and softer sandstone layers of the mountain and in the limestone adjacent to the mountain.

MODE OF OCCURRENCE OF THE CLAY.

From the plain of the Cumberland Valley the mountain rises abruptly in a continuous straight ridge that is broken here and there by water gaps. The clay deposits occur at the northwestern foot of this outer ridge. In the vicinity of Mount Holly Springs they are also found on opposite sides of an interior longitudinal valley—that of Mountain Creek. The clay is associated with beds of sand and colored clays and with the wash from the mountain slope above. It is nearly everywhere accompanied by secondary deposits of iron and manganese ores. The clay was first exposed to view in mining the great iron deposits of this region twenty or more years ago, but its value has only recently become known.

One is inclined to conclude at first sight that the clay is a transported surficial deposit; that it was derived from the decomposition of argillaceous limestone and accumulated at the base of the slope by creep and stream action, and that the iron, having been leached out in the process of transportation, was deposited in the adjacent wash. Careful study, however, shows that most of the accumulations have not originated in this way, although, no doubt, the material in some places has moved down the steep slopes on which it originally lay and is more or less confused with surface wash.

The fact that on the surface the white clay has a definite relation to the upper bed of the mountain sandstone throughout the region is very significant. Almost invariably the sequence in the old mine pits and clay prospects is (1) colored plastic clay containing the iron ore, (2) white clay, and (3) sandstone. At many places the sandstone is decomposed to loose sand, which is quarried for use as building material, but is traceable in depth to hard sandstone, the outermost bed of the mountain rock. No rock exposures occur for several hundred feet from the foot of the mountain in the vicinity of the clay mines, but limestone was reported in mine pits close to the white clay beds, and beyond much doubt the colored plastic clays in which the iron ore occurs is a residuum of argillaceous limestone. The surface relations therefore suggest very strongly that the white clay is also a residual product of some argillaceous sedimentary rock. The fragments of sandstone contained in the clay were probably thin quartzitic layers or lenses in the original rock.

Hopkins states[a] that "the white clay is the direct decomposition product of light-colored hydromica slates which occur intercalated in the Cambro-Ordovician limestone and in the Cambrian slates, sandstones, and quartzite," and mentions several places where he observed the change from clay to slate. The places specifically mentioned—Latimore and Hensingersville—were, unfortunately, not visited by the writer. Latimore is located on the southern edge of South Mountain, in the belt of old volcanic rocks, and the clay there is undoubtedly not at the same horizon as that in the vicinity of Mount Holly Springs, which will be referred to later.

Clear exposures showing a change from clay to hard rock were not seen by the writer, but in several of the deeper tunnels the white clay is hard and has a banded, lamellar structure, resembling slate, and a faint greenish tint. The section in the Philadelphia Clay Company's tunnel positively demonstrates the interbedded relations of the clay. Beyond the loose rock and wash at the entrance the tunnel passes through several hundred feet of gray shaly clay and less altered hydromica schist seamed with limestone, ocher beds, hard brownish altered dolomite, soft yellow clay containing iron ore, a thick stratum of white clay, to the quartzitic wall rock. It is concluded, therefore, that the larger deposits of white clay are original sedimentary beds directly overlying the Antietam sandstone and underlying the limestone of the valley. The "soapstone" used at Pine Grove Furnace in the manufacture of brick is a light greenish sericite schist with quartz phenocrysts, an altered rhyolitic rock similar to other schist seen in the volcanic belt, which crushes readily to a fine white clayey powder and is probably the same as the beds at Latimore, from which the local white clay described by Hopkins was derived. These volcanic schists may be the ultimate source of all the white clay, in which case the later sedimentary white beds were derived from their decomposition and were deposited near the volcanic schist outcrops in early Cambrian time. The clay sediments are certainly variable in thickness and irregular in distribution, but they are thickest in Mountain Creek valley, near the volcanic belt.

Analyses show that the white clays are very siliceous, very low in iron, and high in alkalies. Hopkins compared analyses of white clays with those of hydromica slates from which they were derived, the samples having been taken in adjoining districts, and found that the most noticeable difference was in the greater amount of potash contained in the slates. This difference is due to leaching out of the potash in the process of disintegration. Analyses of two white clays from this area and of the volcanic sericite schist from Pine Grove Furnace are given below.

[a] Ann. Rept. Pennsylvania State College for 1899-1900, appendix, offic. doc. No. 21, p. 11.

Analyses of white clay and original sericite schist.

	Sericite schist, Pine Grove Furnace, Pa. [a]	Crude white clay, Henry Clay, Pa. [a]	Crude white clay, Upper Mill, Pa. [b]
SiO_2	73.45	69.61	84.05
TiO_2	.21	.90	.....
Al_2O_3	13.77	16.83	9.44
Fe_2O_3 (total iron)	2.76	.95	.28
CaO	None.	.11	.23
MgO	1.22	1.51	1.35
Na_2O	.18	.08	.28
K_2O	4.47	3.41	2.37
P_2O_5	.03	.14	....
Loss in ignition	3.08	6.35	2.18
Total	99.17	99.89	100.18

[a] W. T. Schaller, analyst.
[b] Analyzed in the chemical laboratory at the Pennsylvania State College.

DISTRIBUTION.

White clay occurs along the west foot of South Mountain from the Maryland State line to Susquehanna River. In the southern part of the tract the beds are thin and have not been worked with profit. The southernmost opening seen was Mr. Rock's pit, at Tomstown, 5 miles north of the Maryland line, where a small amount of white clay is associated with white sand, which is quarried for building purposes. Old ore pits are numerous in the vicinity and mining on a very small scale was in progress in an adjacent pit. East of Fayetteville clay has been obtained from near Black Gap, and prospects are now owned by Amos B. Lehman, of Fayetteville. Many pockets of the clay are found in the extensive sand deposits quarried south of the pike. Clay is reported by Hopkins along the foot of the mountain from Fayetteville north to Shippensburg, where small prospects occur, but no large bodies of pure clay have been found. The reports of the Second Geological Survey of Pennsylvania on the iron industry of this region, however, show that thick beds are associated with the ore.

The profitable clay industry is centered about Mount Holly Springs, near the east end of South Mountain. Here the clay occurs sparingly along the north face of the mountain and in greater quantity on both sides of the interior longitudinal valley of Mountain Creek. There are a number of abandoned clay workings on the north slope, on both sides of the gap. The clay is rather intimately mixed with sand and is of limited extent, and is probably in part transported from its original bedded relations. At the large sand quarries in the town of Mount Holly Springs, colored clay has been encountered which is used by the Mount Holly Brick and Clay Company in the manufacture of bricks. White clay was seen in several prospects above the Walker sand mine and in the Diven-Holly sand mine, but the deposits appear to be thin. It is also known to occur on the Stuart tract, 2 miles to the west along the mountain, where phosphorous ore (wavellite) in

white clay is now mined by the American Phosphorus Company. The data obtainable indicate that the beds on the north face of the mountain are not thick enough to be mined profitably on a large scale.

The most extensive and valuable clay deposits occur in the valley of Mountain Creek. This valley is a syncline inclosing Shenandoah limestone, nearly all of which has been removed by erosion, or is so deeply weathered that its outcrops are concealed. It has been observed at only a few places in the valley. The clay occurs along the margins of the limestone trough next to the quartzite of the mountain. The same clay belt extends over the divide into the small valley draining eastward, where a mine is in operation. Elsewhere along the slopes of the mountain, farther east, there are scattered prospects, but only those associated with the abandoned iron pits south of Boiling Springs were visited by the writer.

CLAY MINES IN OPERATION.

The operating clay mines are all located in the valley of Mountain Creek and its extension over the low divide to the east. As stated above, numerous undeveloped prospects and abandoned clay pits occur along the mountain front in the vicinity of Mount Holly Springs, and a small amount of clay is mined at the sand pits in the town.

Cumberland Clay Company.—The eastern end of Mountain Creek valley east of Upper Mill has been extensively prospected by the Cumberland Clay Company, J. L. Musser, manager, which has opened a mine on the north side of the valley. A test shaft 150 feet deep was sunk in a prospect near the sandstone outcrop, all but 23 feet of which was reported to be in white clay. About 70 feet below this opening a tunnel runs northward into the mountain. This had been driven in about 225 feet at the time of the writer's visit, but according to reports is now in about 350 feet, and at its end a branch drift has been run about 175 feet eastward in the clay. Some of the clay, possibly a considerable portion, is white and of good grade. The shaft above will soon be connected with this tunnel as an air shaft and means of escape. It is reported that the sandstone wall in the west branch of the tunnel was pierced and found to be but 2½ feet thick, and that gray and white clay again occur back of it. The sandstone is probably a thin bed in the slate overlying the main sandstone.

The main working tunnel, which is fitted with a gravity tramroad, is 156 feet lower. This was 650 feet long when visited, but is now reported to be 864 feet long and to terminate in the white clay. About 800 tons of crude clay have been mined and shipped recently from this property and about 500 tons more are ready for shipment. Some of the clay is hard and compact and shows slaty cleavage, but is nevertheless of high grade.

The gravity tram conveys the clay to the plant, which was in process of construction when visited. The building, six large cement

settling tanks, and two water tanks were already constructed. It is planned to handle the clay from washers through flotation troughs into the settling tanks by gravity. The capacity is to be 100 tons a day. The refined clay will have to be hauled by wagon nearly one-half mile to the railroad siding.

Hopkins reports that clay was mined at the old Medlar ore bank, just south of upper mill, by the Mount Holly Brick and Clay Company during 1898 and 1899, but that work there was abandoned probably because the supply was exhausted.

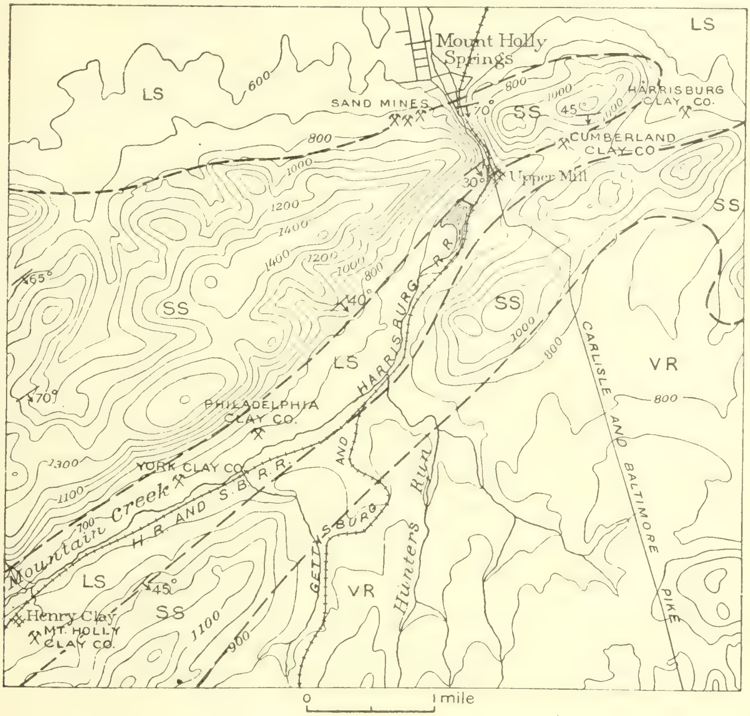

FIG. 12.—Map of South Mountain in the vicinity of Mount Holly Springs, showing the clay mines and the rock formations. VR, pre-Cambrian volcanic rocks: SS, Cambrian sandstone and shale; LS, Cambrian limestone.

Philadelphia Clay Company.—The main body of clay thus far discovered in the region occurs along the north side of Mountain Creek from the gap westward to Henry Clay. The Philadelphia Clay Company, located at the old Crane ore bank, is the most important mine in the area, and its property extends from the Mount Holly Paper Company's land at the gap to the York Clay mine, $1\frac{1}{4}$ miles west. Mr. S. R. Still, the manager, courteously showed the writer the mine and works and gave all information desired.

The clay was originally prospected along outcrops in the old mine pits on the upper slopes and by a tunnel 100 feet above the present opening. The mill is located about 60 feet above the creek and is

reached by a spur from the Hunters Run and Slate Belt Railroad. The main tunnel enters on the level of the mill and extends about 1,000 feet into the mountain to the sandstone "wall" rock. Beyond the several hundred feet of surface wash at the entrance there are 200 to 300 feet of gray shaly clay and altered sericite schist, 30 to 40 feet of yellow ocher, 10 to 15 feet of hard yellow dolomite, 65 feet of iron ore in clay, and about 200 feet of white clay, streaked with iron near the ore, but largely pure white. The clay contains grains and scattered masses of white sandstone up to 2 feet across and occasional beds and streaks of white sand. The mountain sandstone lies back of the clay, but was not seen by the writer because the part of the tunnel that reached it had been mined out and caved in.

The white clay in this mine is at most places saturated with water and as soon as it is encountered yields water freely, which carries the clay with it. The flow of water here is incessant, but the grade of the tunnel is steep enough—1 in 12—to carry it off quickly. When ponds in old ore pits are tapped the sudden flooding of the mine is a source of danger to the workmen. It is impossible to keep a drift in the white clay open for any length of time, because the irresistible pressure of the semifluid clay breaks the timbers and a cave-in results. It is said that the life of timbers in the white clay is but three weeks. Consequently the permanent drifts for tramways are maintained in the yellow clay just outside the white clay.

The main tunnel enters normal to the mountain with a grade of 1 in 12, and at the outer edge of the clay lateral drifts branch off in both directions. As these are to be permanent drifts for tramways they are driven in the yellow clay outside the white. From these lateral drifts crosscuts or working entries are driven at intervals of 60 feet through the clay to the wall rock.

The Philadelphia Company's method of mining is different from that in use in the other mines visited, because the deposits are peculiarly situated. They outcrop high up on the steep slopes of the mountain and stand nearly vertical, so that they can be mined like veins, by stoping up along the bedding from a tunnel beneath. Stoping is begun at the farther end of one of these entries for about 30 feet on either side until a large room is opened, when the props and pillars are removed and the clay soon crumbles or flows in. It usually continues to flow in until the clay overhead is exhausted and the wash from the surface, several hundred feet above, comes down, but sometimes further stoping is necessary. About 1,000 mine carloads are obtained from a single stope in this way, and as high as 4,000 are reported.

When the stope is exhausted the drift is robbed back and another stope is opened and worked in the same way, and this is continued

until the entire width of the clay belt is mined. The adjoining crosscuts are then mined in the same way. By this method a distance of 250 feet to the north of the main tunnel and 700 feet to the south have been mined out.

The white clay belt is variable in width, ranging from 120 feet to 400 feet in places, which makes the lateral tramway drifts very crooked and long, and it is the intention of the company to construct a new diagonal tunnel to intercept the farthest workings at the south and thus furnish a direct outlet for the tram cars.

The Philadelphia Company's mill and mine are the largest and best equipped in the region. The mill is a long, low building located just below the mouth of the tunnel. The mine cars bring the crude clay to the upper floor, where it is shoveled into blunger mills and churned with pure filtered mountain water by a set of oppositely revolving paddles. After thorough mixing it passes as a milky liquid or slip over inclined tables of fine wire screen, which oscillate rapidly sidewise and remove the coarser particles of sand. The slip is then run over steeply inclined screens of very fine silk bolting cloth, 200 meshes to the inch, or finer, the clay and water playing upon them from jets above. Only the impalpable clay passes through, the coarser material sliding off on the surface. This patented process produces the clay of the finest grade, but the waste from it is excessive. It is unfortunate that some use can not be made of the fine clayey sand that is now poured out on the great white dump that disfigures the landscape.

The purified slip is collected in large vats and distributed to the settling tanks, where bluing is added to whiten the clay. After standing twenty-four hours the water is drawn off from the top and is used again. The thick slip in the bottom of the tanks is pumped into filter presses and forced in until 160 pounds pressure is obtained and kept at this pressure until the water ceases to run out. These presses are made of a series of double concave iron plates, 2 feet square, with vertical grooves on the concave surfaces. A double sheet of heavy canvas is placed over the surface of the plates to let the water out and to prevent the clay from adhering to the iron. The clay slip is forced into the presses through a hole in the center of the plates, and when the spaces are filled and pressure is exerted the water passes through the canvas and down the grooves in the plates. The molded corrugated cakes of clay, 1½ inches thick, are conveyed by belt to a tile machine, where they are remolded into 6-inch tiles 3 feet in length, so they will dry rapidly in the ovens, to which they are carried by small cars.

The clay is sold either in bulk, in small pieces, or pulverized, in bags. About one-half the output is pulverized. The mill has a capacity of 100 tons a day and an average production of 60 tons. It

is equipped with 6 blunger mills, 7 oscillating screens, 104 bolting-cloth screens, 17 settling tanks (some of 30,000 gallons capacity), 16 filter presses, and 15 ovens of 12 cars capacity each. The value of the clay is reported to be $5.50 a ton. A royalty of 25 cents a ton of refined clay is paid to the owner of the land.

York Clay Company.—The mine of the York Clay Company adjoins the Philadelphia mine to the west. The mill was examined, but not the mine, as the manager, John Allen, was absent at the time of the writer's visit. The practice here has been to mine by large shaft to the maximum depth profitable, which is about 90 feet, and then abandon this for a new shaft. At the time of the writer's visit the company was operating in a round shaft 21 feet across and 50 feet in depth, with steam bucket hoist. The clay is hauled by wagon 700 feet to the mill. The company also has a tunnel 150 feet into the mountain to the clay and a drift along the bed 250 feet. Stoping had been carried 20 feet above the tunnel. A small amount of iron ore was passed through before reaching the clay. The beds seem to lie flatter here than at the Philadelphia mine, although it may be that the drifts have not yet been carried back far enough to strike the original bedded deposit.

The product is refined in the company's mill on the property. It first passes through two washers fitted with vertical paddles and then one with horizontal paddles, from which it flows as a thin slip through about 400 feet of very gently inclined flotation troughs built side by side in 50-foot lengths. The sand is deposited in these troughs and is removed by shovel, the clay remaining in suspension. The slip is further filtered through revolving wire screens and collected in settling tanks, of which there are five. After about two days the clear water is drawn off and the thick slip is forced through presses, 3 in number, similar to those of the Philadelphia Clay Company. The corrugated cakes are transferred by cars directly to the drying tunnel, which is heated by steam pipes to 190°. The dried clay that is not sold in bulk is pulverized in an old thrashing machine, with a cup chain attachment which delivers the powder into a vertical bin for bagging. The capacity of the mill was reported to be between 10 and 13 tons a day.

The Mount Holly Brick and Clay Company.—Through the courtesy of the manager, Charles Blissard, much information regarding the plant and mines of this company was obtained, and the property was carefully inspected. The brick plant and clay refinery are located in the town of Mount Holly Springs, where they were constructed with the expectation that the clay mined in the vicinity of the town would furnish an amply supply for operating the refinery and that the siliceous waste and impure clay could be used in the brick plant. The supply of white clay, however, was soon exhausted, and in 1898

the company opened up the deposits at the old Medlar ore bank, at Upper Mill, and the Henry Clay deposits, 4 miles above, on the south side of Mountain Creek. The Medlar pit has since been abandoned and the company gets its supply solely from Henry Clay, paying a royalty of 10 cents a ton, which makes the cost of crude clay at the mine about $1.30 a ton.

The Henry Clay mine is operated by drifts from a shaft 47 feet deep in the rear of the old ore pit. The main drift runs 125 feet southeastward from the shaft, and from its end lateral drifts parallel to the mountain branch off. A large amount of pure clay is exposed in these drifts and is being mined by side entries and stoping. In a minor drift, 100 feet long, which runs northwestward from the shaft toward the valley, the white clay is mixed with yellow clay and iron ore, and the purer portions have been largely mined out. This part of the deposit may not be in its original position, for it may have moved down the slope and become intimately mixed with the overlying clay and iron ore, but the portion in the southeast drift is probably in its normal position beneath the iron-bearing clay. It appears to lie flat or to rise gently eastward and probably forms the east side of the syncline. The mine is equipped with steam hoist and tram cars. As now operated its capacity is 33 tons a day, all of which is used by the brick plant at Mount Holly Springs in the crude dried form, none being refined at present.

On the opposite side of the old ore pit, about 150 feet northeast of the clay opening, a shaft had been sunk 71 feet in ore-bearing clay, which was being mined for iron by the company, which had installed for this purpose a steam bucket hoist, an ore washer, and a gravity tramway to the railroad siding. About 15 tons a day were being mined.

The refinery at the brick plant has a capacity of 30 to 40 tons a day and is furnished with three triple vertical blungers with revolving vertical slatted grates, long flotation troughs, rotary fine wire screens, 10 settling vats, 10 presses, and a 12-track tunnel drier. The siliceous waste extracted by the refinery process was found to be too short grained to make into bricks; in fact the crude clay itself needs a binder of plastic clay to give it body, and since the production from the mine is no more than sufficient to supply the brick plant, the refinery has been shut down for some time.

The Mount Holly Company makes an excellent hard, semivitreous brick, for which there is a ready market at the price of $20 a thousand. The light color of the bricks, cream to light buff, makes them very desirable for the fronts of buildings, while their hardness meets the requirement for paving.

The clay from the mine at Henry Clay has the necessary ingredients to produce a vitrified brick, but has not enough body to hold its shape

without cracking when being burned. Other clays sufficiently free from iron and manganese not to burn red must be mixed with it to give it cohesiveness. Purple clays from the sand mines at Mount Holly Springs and black clays from the northeast side of the gap are used to a small extent, but a large part of the binder comes from New Jersey and Maryland. The color of the black clay is due to organic substances, which burn off in the kiln. Because of the siliceous character of the crude white clay additional sand is not needed, but a certain per cent of grog (ground brick) is added.

The material is first ground in a dry pan, an iron cylinder with two large iron wheels or mulls, which revolve when the bottom of the cylinder is rotated. The powdered material is conveyed from the bottom by pan elevators to a revolving sieve, from which the tailings automatically return to the dry pan. The screened mixture passes to the temperer or pug, a horizontal rotating mixer, where water in the form of steam is added, and is then delivered by gravity to the top of a brick machine, in which 2 vertical and 2 horizontal augers thoroughly mix the clay and destroy grain. The brick column is conveyed by a continuous belt to the cutter, the speed of which is automatically regulated by the speed of the belt. Fifteen bricks are cut at a time, and are separated by passing onto a belt moving with greater speed. They are fed by hand into two double pressing machines, where they are shaped under light pressure and stamped "Mt. Holly." If bricks are delivered too rapidly to be pressed, the surplus are returned to the pug by elevator and belt.

The bricks are dried in a 12-track steam drier 128 feet long. The cars, which carry 440 bricks each, are run into the drier at one end and removed at the opposite end, taking about two days in the passage. The temperature is 140° at the ends. The bricks are finally fired in down-draft kilns with large smokestacks at the ends. The furnaces, with small smokestacks, are on the sides. Five kilns were in operation, the largest of 188,000 capacity, with a total capacity of 600,000 per month and an output of between 400,000 and 500,000 a month. The kiln is fired to cone 8 (2,354°) in the upper part, and the burn is completed in about a week.

Laurel Forge and Pine Grove Furnace.—At Laurel Forge, 1 mile above Henry Clay, pure white clay occurs in abandoned iron pits, where it is now mined on a small scale and used in the manufacture of brick by the Fuller Brick and Slate Company, of Pine Grove Furnace, 2 miles farther up the valley. It is mixed with pale-green sericite schist, locally called "soapstone," for the manufacture of light-colored pressed brick. Red pressed bricks are now being made from local red clay and black slate by the South Mountain Mining and Iron Company, Allen Butler, superintendent. The bricks are dry pressed, and

although handsome and ornamental they are more absorbent than the vitrified brick made of the Henry Clay stock.

Harrisburg Clay Company.—The Harrisburg Clay Company works the only active mine outside of Mountain Creek Valley. It is in the same general syncline, however, just over the divide from that of the Cumberland Clay Company. Although it is a small plant it produces clay of very high grade, said to be as pure as any in the district.

The mine is on low ground and is operated by a short incline and tunnel running in about 20 feet to the clay and 60 feet west with the clay. It is operated by tram and steam hoist. The bed of clay appears to be rather thin and not much stoping can be done. If it is a bedded deposit, the formations must lie nearly flat in the bottom of the syncline, but it may have moved to this position from the steep slopes above. Another tunnel was started farther south, but had not yet reached the deposit. The clay is hauled by wagon several hundred feet to the refinery, which is equipped with 1 horizontal washer similar to the screw-and-blade type of ore washer, flotation troughs, 2 settling tanks, 2 presses, and 2 ovens of 20 cars capacity. The production of this plant is about 7 tons a day, which has to be hauled one-half mile to the railroad.

USES OF WHITE CLAY.

Paper manufacture.—Pure white clay, such as is obtained from the South Mountain factories, is used chiefly in the manufacture of paper. Wall paper, the cheaper writing papers, and all paper requiring a smooth, absorbent surface for fine printing are made in part of clay, or some other mineral, such as pulverized calcium sulphate or barium sulphate. The advantages of the South Mountain clay over other substances for this purpose is its white color, freedom from iron, fine grain, absorptiveness, and its light weight, which causes it to remain in suspension. The clay is made into a thin cream with water and a small amount of resin sizing to make it adhere to the fibers of the paper body, and is fed into the paper-machines with the pulp. The amount of clay should not exceed 10 per cent in paper for permanent publication, but for chromolithographs and publications of temporary value, 35 to 40 per cent of clay may be used, as the ink is absorbed more rapidly and the impression is clearer.

Brick and tile manufacture.—Excellent building brick of light color are made from the unrefined clay, but it requires an admixture of a more plastic clay to give it body. The potash which it contains causes it to fuse readily, and the brick acquires a semivitreous texture, which makes it both hard and impervious—qualities which adapt it to street paving and to exterior finishing. Its pleasing color also adds to its attractiveness for building purposes. The Mount Holly Brick

and Clay Company are engaged in the manufacture of such brick, and the Pennsylvania Tile Works, at Aspers (Bendersville station, on Gettysburg and Harrisburg Railroad), was reported by Hopkins to be manufacturing white encaustic or enameled tile. The South Mountain Mining and Iron Company, of Pine Grove Furnace, is manufacturing unvitrified pressed brick.

Other uses.—As pointed out by Hopkins, the white clay possesses many of the requirements of the potter's mixture for china ware. Although it is more siliceous, higher in potash, and less plastic than ball clay, which is the clay used in pottery manufacture, the proper mixture apparently can be readily obtained by adding to it correspondingly less silica and feldspar than is customary, the exact proportions to be determined by chemical analyses. The plasticity and cohesiveness may also need to be increased by the addition of a small amount of ball clay, as for brick manufacture.

It is known that white clay is used as an adulterant in various substances, especially in paint. Some of the clay from this area may be sold for this purpose. Hopkins also mentions that some of it is used for calcimining, for which it is well adapted.

CLAYS AND SHALES OF CLARION QUADRANGLE, CLARION COUNTY, PA.

By Edwin F. Lines.

INTRODUCTION.

Both clays and shales are abundant within the Clarion quadrangle. Shales that are probably suitable for the manufacture of brick and tile are scattered over most of the region, and in some places are readily accessible to lines of transportation. The clays include both the flint and plastic varieties, but the latter have been little worked. The workable deposits of flint clay so far known are confined to the northern part of the area. This clay was formerly shipped to a considerable extent as raw material, although it had to be hauled several miles by wagon to the railroads, but it has not been mined for some time, and the old strippings are now largely covered up. There has been a recent revival of interest in the clay, however, as a result of the beginning of the construction of a new railroad which will pass near some of the best deposits.

LOCATION AND AREA.

The Clarion quadrangle is in Clarion County, except a few square miles in its southeast corner, which extend into Armstrong County. Its north boundary passes just south of Shippensville, the south through New Bethlehem, the east a short distance within the east county boundary, the west just west of Sligo. The quadrangle comprises approximately 225 square miles, a little more than one-third the area of Clarion County.

GENERAL STATEMENT.

The rocks of the quadrangle in which the clays and shales occur are included in the Allegheny formation (or Lower Productive Coal

Measures) and the Pottsville formation. The succession of rocks is as follows:

Relative positions of beds in Allegheny and Pottsville formations in Clarion quadrangle, Pennsylvania.

Allegheny formation:	
Coal (Upper Freeport)	
Plastic clay	
Limestone	
Flint clay	
Shale and sandstone	130 feet.
Coal (Lower Freeport)	
Plastic clay	
Limestone	
Shale and sandstone	
Coal (Upper Kittanning)	
Plastic clay	
Shale and sandstone	
Coal	
Plastic clay	
Shale and sandstone	
Coal (Middle Kittanning)	
Plastic clay	110 feet.
Shale	
Coal (Lower Kittanning)	
Plastic clay	
Coal (Lower Kittanning?)	
Flint and plastic clay	
Shale and sandstone	
Limestone	
Sandstone	
Shale	
Coal (Upper Clarion)	
Plastic clay and shale	60 feet.
Coal (Lower Clarion)	
Plastic clay	
Shale	
Coal (Brookville)	
Clay	
Pottsville formation:	
Sandstone (Homewood).	
Shale, coal, plastic and flint (?) clay (Mercer).	
Sandstone (Connoquenessing).	

The figures showing the thickness of the groups represent a fair average but are not intended to be final.

A glance at the table shows that eleven clay horizons are associated with the same number of coal horizons, the clays underlying the coals. Two and possibly three of the clay beds contain flint clay. It will be noted that two of the coals are designated Lower Kittan-

ning. Whether the lower seam is a split from the upper or an extra seam is uncertain. The lower coal lies from 4 to 17 feet, and in some places perhaps more, below the upper. The lower bed appears to be coterminous with the flint clay of this horizon, as the coal was not identified at any locality outside of the boundaries of the area occupied by the flint clay.

SHALES.

The only shale now in use in the area is the one below the horizon of the Clarion coal. This shale is exposed in the pit of the Canton Tile Hollow Brick Works, west of New Bethlehem, described below. Other deposits of shale that are accessible to railroads were noted as follows:

At the railroad crossing between Fairmount and Hawthorn; thickness 30± feet.

In hill above Underwood mine at Ore Bank station, on the Sligo Branch of the Pennsylvania Railroad; thickness 50± feet.

In hill above Baldauf No. 1 mine, on a branch of the Pittsburg, Summerville, and Clarion Railroad; thickness 30± feet.

The exposures just mentioned are typical and are readily accessible for examination. In general, however, smaller but numerous and widely scattered outcrops indicate that a considerable thickness of shale lies nearly everywhere above the Lower Kittanning coal.

PLASTIC CLAYS.

Mercer horizon.—Beds at the horizon of the Mercer shale outcrop above drainage level along Clarion River, in the lower portion of Leatherwood Run, at Sligo, and just west of Mayport, but no good exposure of clay was noted at this horizon except small exposures at Mayport.

Brookville horizon.—The clay at this horizon was seen at only a few places and probably is not important.

Clarion horizon.—In some parts of the quadrangle there are two coals and two accompanying clays at the horizon of the Clarion coal. A section in a run near the schoolhouse, about 1 mile northeast of the Zion churches, shows 5 feet or more of white clay below each of the two coals. At the road fork, one-half mile south of Rockville, a 15-foot bed of clay is exposed beneath a coal blossom, probably Clarion. On Leisure Run, 4½ miles north of New Bethlehem, 10 feet of the same clay shows above the run and below a 16-inch coal blossom. In the vicinity of New Bethlehem this clay is now used in connection with the overlying shale by the Canton Tile Hollow Brick Company in the manufacture of hollow building brick and drain tile.

A section made in the pit of this company is as follows:

Section of pit of Canton Tile Hollow Brick Company.

	Ft.	in.
Olive fissile shale, stained red	3	0
Carbonaceous layer (Clarion coal blossom ?)		4
Sandy ledge		10
Dark-drab shale	18	0
Drab plastic clay, soft	5	0
Drab plastic clay, hard, siliceous	5	0
Olive sandy shale	10	0
Sandstone.		

Kittanning horizons.—At some localities there are at least four Kittanning coals, each underlain by a clay bed. The upper clay beds so far known are unimportant. The plastic clay below the lower Kittanning coal is undeveloped, but road crops and mine sections throughout the quadrangle indicate that it is persistently present and probably of sufficient thickness for mining. Among the best road exposures is one a quarter of a mile east of Jack schoolhouse and about 4 miles northwest of New Bethlehem, where 3 feet of reddish stained clay outcrop, and one 1 mile east of Mechanicsville, where 8 feet of light-drab clay are exposed. The following sections, comprising 2 feet or more of clay, were measured below the Lower Kittanning coal in country banks and mines:

A. V. Confer coal bank, just east of Strattonville; 3 feet, apparently of good quality.

Coal bank on Lewis Deitz farm, 3½ miles northeast of Sligo; 2 feet, of excellent appearance.

J. K. Andrews coal bank, on James Myers farm, 3 miles northeast of Sligo; 3 feet 10 inches.

Country bank on Charles McCall farm, 3½ miles northeast of Rimersburg station; 6 feet, light gray clay.

Country bank 2 miles northeast of Wild Cat; 2½ feet, quite free from sand.

Only a partial thickness of the clay was seen at any of the above places, but the measurements are suggestive of considerable deposits of clay at this horizon. At Huey, just over the west boundary of the quadrangle, is a drift in which 7½ feet of clay were measured, both the top and the bottom of the section being concealed. The thickness of the clay here indicates that a good deposit may be found along the Sligo branch of the Pennsylvania Railroad wherever the clay occurs above drainage. The plastic clay from the Lower Kittanning horizon could be prospected with a view to brick or pottery manufacture.

The other clay in use from the Kittanning horizons is the one next higher, or the Middle Kittanning. This clay is used by the Hawthorn Pottery Company in the manufacture of Bristol glazed stoneware. The supply is obtained from a stripping just north of Hawthorn. The clay here lies under 4 to 10 feet of cover and varies in thickness from 4 to 6 feet. The upper part of the bed is soft, rather free from

sand, and has a chalky appearance due to weathering, while the lower part is harder and rather sandy and is greenish in color. The softer and more plastic portion of the bed is used as it comes from the bank in the manufacture of small pieces, but the hard portion is washed free from sand and used for large ware. At the time of the writer's visit the clay below the Lower Kittanning coal had been used experimentally, but no definite results had been obtained. The Middle Kittanning clay was formerly stripped on Town Run, opposite the opening of the No. 2 mine of the Alcola Coal Company. The quality of the clay here is reported to be excellent for pottery manufacture.

Freeport horizons.—Plastic clay occurs below each of the Freeport coals, but beds at these horizons are comparatively limited in area and few good opportunities were offered for measuring sections. The best section noted was in a country bank just west of Hickory Ridge schoolhouse, where 3 feet were exposed below the coal.

FLINT CLAYS.

Mercer horizon.—No good exposure of flint clay was seen at this horizon within the quadrangle. Just south of it, however, at Climax and St. Charles, flint clay from this horizon is used in making high-grade fire brick.[a] At one point within the quadrangle—viz, on the west side of Leatherwood Run, about 1 mile north of St. Charles—fragments of flint clay, which are probably from this horizon, have been found in a field, but several prospect holes sunk here failed to find the source of the fragments.

Lower Kittanning horizon.—Flint clay occurs below the Lower Kittanning coal in a belt that extends across the north half of the quadrangle with a width of 1½ to 2½ miles on each side of Clarion River, except in an area north of Clarion. Owing to the height of the clay in the hills, however, only a relatively small portion of the area is actually underlaid by it. The clay is persistent in its occurrence, but varies greatly in quality. It has been used to considerable extent, so its qualities are fairly well known. The best clay is light yellowish brown in color, fine grained in texture, and moderately hard. Weathered pieces are bluish gray on exposed surfaces and are easily broken. The following chemical analyses, made by P. H. Bates, of the United States Geological Survey's laboratories for testing structural materials, at St. Louis, Mo., indicate the quality of an average sample of this clay.

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[a] Bull. U. S. Geol. Survey No. 279, p. 162.

Analyses of air-dried samples of flint clay from C. B. McQueen farm, Clarion County, Pa.

ULTIMATE ANALYSES.

	A.	B.
Silica (SiO_2)	58.96	56.46
Alumina (Al_2O_3)	25.60	27.69
Ferric oxide (Fe_2O_3)	3.32	2.55
Manganese oxide (MnO)	.07	.09
Lime (CaO)	.70	.42
Magnesia (MgO)	.25	.28
Sulphuric anhydride (SO_3)	.07	.14
Soda (Na_2O)	.15	.06
Potash (K_2O)	.36	.52
Water at 100° C	.80	1.40
Ignition loss	9.90	10.64
	100.18	100.25

RATIONAL ANALYSES.

	A.	B.
Free silica	25.75	20.50
Clay substance	59.00	64.50
Feldspathic substance	4.50	3.00
Ignition loss	10.75	12.00
	100.00	100.00

The samples thus analyzed were taken from a 3-foot section in a new drift made by the Sligo Fire Brick Company. Sample A represents the upper 1 foot, and sample B the lower 2 feet of the section. Sample A is siliceous in appearance, shows a rough surface, and breaks irregularly rather than with the conchoidal or shell-like fracture that is characteristic of flint clay. Sample B is like the type of best clay described above except that instead of being homogeneous it contains a small percentage of bluish inclusions. In some places it shows streaks that resemble bedding planes. Wherever cracks occur in the clay the surfaces formed by them are strongly stained with iron. The high percentage of iron shown by the analyses makes a good deal of the clay unsuitable for use in the manufacture of refractory materials. The clay in the bank from which the samples were taken for analysis is used by the Sligo Fire Brick Company in the manufacture of fire brick. Clay taken from below the Brookville(?) coal in the mine of the Sligo Coal and Coke Company is used as a bond. The bricks are sold principally for use in open-hearth furnaces. The reported criticism of bricks made from this clay is that while they will stand relatively high temperatures they are deficient in resistance to friction.

The quality of the clay varies from place to place. The clay south of Clarion River appears to be, on the whole, better than that north

of the river, and when it was stripped for shipment its price averaged 40 cents more a ton than that of the latter. In comparing these prices, however, it should be noted that shipments from the northern area probably involved the payment of higher freight rates. Clay from the area north of the river has not been used south of the Wagner and Bell farm, the reported reason being that the clay in that region contained so much iron that it is worthless as a refractory clay. In the area south of the river the best clay is reported to have been taken from the Finnefrock farm. Considerable amounts of clay have also been taken from the Miller farm, located within 2 miles of the Sligo Branch Railroad. The clay on the Finnefrock and Winkler farms, south of Piney Creek, and on the Mowry farm, north of it, is within 1½ miles of a new railroad now being built by the Lake Shore and Western from Franklin to Clearfield.

The following detailed descriptions of occurrences are given for the purpose of assisting prospectors:

Clarion Junction, one half acre stripping on each side of the pike.

Clarion Junction, southeast of, on F. M. Shannon farm. (Reported.)

Clarion Junction, 1½ miles southwest of; open pit on portion of John Rapp farm, now owned by the Niles Fire Brick Company. There is a 3-foot exposure of clay here, and an examination of the face showed that much of the clay had inclusions of impurities.

Clarion Junction, 2½ miles south of, on Wagner and Bell farm; old stripping uncovering about one acre. No clay was exposed here, but the clay formerly mined was reported to be of fair quality.

Piney, 2½ miles east of, on C. W. Mowry farm; prospect hole revealed 3 feet or more of fair-looking clay.

Piney, 2 miles southeast of, on P. B. Finnefrock and D. C. Winkler farms; several acres of clay have been stripped, but very little is now exposed. The bed is reported to average 4 feet in thickness. In the hill on the U. S. Oppelt farm, south of the Finnefrock stripping, the clay is reported to be present also, although it has not been used.

Piney, 2 miles southwest of, on T. N. Whitman farm; old stripping in which clay was reported to average 3 feet in thickness.

Sligo, 2 miles north of, on C. B. McQueen farm; stripping and newly opened drift; average thickness about 3½ feet. A detailed description of this clay is given on p. 340.

Sligo, 1¾ miles north of, on J. B. Miller farm; numerous old strippings.

Sligo, 2½ miles northeast of; newly opened stripping on Mike Howard farm; exposed thickness 2 feet; reported thickness 5 feet. In two places just north of this point about one-half acre has been stripped.

Mechanicsville, 1 mile north of, on Clark Potter farm, now owned by Charles F. Heidrick, president of the Pittsburg, Summerville and Clarion Railroad; prospect hole shows 4 feet or more of clay of inferior quality.

In addition to the openings described above, the presence of the clay was indicated by outcrops in the roads in the following places:

Clarion Junction, 1 mile west of, on road running south to Piney. It is roughly estimated that between 10 and 15 acres in this vicinity are underlain by clay within 8 or 10 feet of the surface.

Manor school house, one-fourth mile east of; bed under little or no cover.

Shippensville, 3 miles south of, on road to Piney, near top of rise; bed under light cover.

Elk City, 3½ miles south of; bed at top of rise under light cover.

Piney, 2½ miles southwest of, and Zion churches, 1 mile northeast of; a few fragments.

Piney, 2½ miles southeast of, on road leading to Five Points schoolhouse.

Sligo, 2½ miles northeast of and just southwest of schoolhouse; clay apparently of excellent quality.

Reidsburg, 1 mile north of, on road to Clarion.

Clarion-Williamsburg, road between; clay shows at several places, at some in considerable thickness, but of inferior quality.

Mechanicsville, 1½ miles northwest of, on road to Clarion; 2 feet exposed.

Mechanicsville, one-half mile east of, south of crossroads; inferior quality, black and knotty.

Mechanicsville, 1 mile east of, on road to Waterson station; 3 feet exposed.

Mechanicsville, 1 mile east of, on north and south road at top of hill; bed under light cover.

Clarion-Strattonville, road between; several exposures.

Strattonville, 1½ miles south of, and Rehoabeth Church, one-quarter mile west of; 2 feet exposed; inferior.

Strattonville, 2 miles northeast of, on road to Fisher, at top of rise; bed under light cover.

Strattonville, 2 miles northeast of, near schoolhouse; small showing, but clay apparently of excellent quality.

Clay workers will appreciate the difficulty of attempting to pronounce judgment on a clay from a field examination of an outcrop. Only such comments are made on the outcrops above noted as are obviously justified, the object being to call the attention of those who are interested to the occurrences of promising clay beds.

Upper Freeport horizon.—Present indications do not show that the flint clay from the upper Freeport horizon is important. Note was made, however, of the following occurrences of this clay:

Rimersburg, 1 mile north of, at road fork; good outcrop near top of hill.

Piollett, 1 mile west of; fragments at top of hill.

Frostburg, 2 miles southeast of, on ridge road; fragments.

Truittsburg, 2 miles northeast of; outcrop of inferior quality.

COMMERCIAL DEVELOPMENT.

At present there are three clay-working plants in the quadrangle, viz, the Canton Tile Hollow Brick Company, the Hawthorn Pottery Company, and the Sligo Fire Brick Company, the character of whose products has already been stated. In the future development of the clays of the quadrangle the flint clay from the Lower Kittanning horizon seems to offer the greatest possibilities. Although this clay is not equal in quality to the best flint clays on the market it nevertheless makes a fairly good fire brick. The writer does not know that experiments have been made in the use of plastic clay from the same horizon as a bond, but observation of outcrops indicates that if the clay were to be used on the spot the plastic clay accompanying the flint at most places would be sufficient, in quantity at least, to furnish the necessary bond.

Coal and natural gas are available in nearly all parts of the region, affording efficient and cheap fuel. Prices of natural gas for commercial use, quoted to the writer, range from 8 to 22 cents per thousand feet. An idea of freight rates may be obtained from the following quotations from Sligo:

Sligo to Pittsburg, \$1.40 per ton for clay and \$1.60 for brick.

Sligo to Buffalo, \$1.60 per ton for both brick and clay.

CLAYS AND SHALES OF SOUTHWESTERN CAMBRIA COUNTY, PA.[a]

By W. C. Phalen and Lawrence Martin.

INTRODUCTION.

Area.—The area here considered is the Johnstown quadrangle of the United States Geological Survey, comprising 228 square miles in southwest-central Pennsylvania. Though mostly in Cambria County, it includes small parts of Indiana, Westmoreland, and Somerset counties.

Geology.—The rocks that outcrop in this district are mostly of the Carboniferous system, but a few hundred feet (400±) of Devonian rocks are present. Of the Carboniferous rocks only those of the Pennsylvanian series are of interest, for, except the Pleistocene and later clays, all the valuable clay deposits seem to be confined to this series. As developed in this area the Pennsylvanian series comprises the Pottsville, the Allegheny, and perhaps all or nearly all of the Conemaugh formation—in all, about 1,200 feet of beds. These formations correspond to the Pottsville conglomerate or Millstone grit, the Lower Productive, and Lower Barren Coal Measures, respectively, of the Second Geological Survey of Pennsylvania.

THE CLAYS.

The clay materials of this region are flint clays, plastic clays (including some fire clays), and shales.

GEOLOGICAL POSITION OF THE CLAYS.

Flint clays are found at three and possibly more horizons. The highest flint clay occurs in the Conemaugh formation and varies in position in the Johnstown district from 50 to 100 feet above the Upper Freeport coal (known also as the "E," Coke Yard, "Four-foot," and Lemon seam), and usually lies near the top of the Mahoning sandstone. In the Blacklick Creek district, west and southwest of Wehrum, a flint clay has been observed at many places in a similar position with reference to the Mahoning sandstone and is probably to be correlated with the flint clay occurring about Johnstown.

[a] These notes are preliminary in nature. A more detailed account of the clay resources of the Johnstown quadrangle will be published later.

In the Allegheny formation flint clay was observed in the northwest section of the area, in the valley of Mardis Run. It occurs about 25 feet below what is presumably the Upper Freeport coal, and hence may correspond with the Bolivar fire clay of the region farther southwest.

The most important flint clay is that occurring at the Mercer horizon, in the Pottsville formation, in the South Fork district.

Plastic clays have been observed at many horizons in this region. At only a few places, however, is the position of the beds with reference to transportation and their thickness such as to make them of great economic importance. A few unimportant plastic clay beds have been observed in the Conemaugh formation. Many of the coals in the Allegheny formation are underlain by plastic clays. The clay below the "E" coal is at some places of workable thickness, though it is not comparable with that below the "B," or Lower Kittanning, or Miller seam. Below the limestone bed associated with the Upper Kittanning coal (known also as the cement or "C′" coal) a deposit of clay was noted at some points about Johnstown. The plastic clay lying below the Miller coal is the most valuable in the region. It varies from 4 to 12 feet in thickness. This fire clay has been extensively exploited about Johnstown and to a less extent about South Fork. Along Blacklick Creek, in the northern part of the area, the clay at this horizon is of workable thickness, but, so far as known, has never been utilized.

The lowest plastic clay in this region is found at the Mercer horizon, though, as indicated above, a flint clay lies at this horizon at some places.

The valuable shales in this area appear to be confined chiefly to the Conemaugh formation, though important beds may occur in the Allegheny and Pottsville. In the Johnstown district valuable shale beds occur in the lower 300 feet of the Conemaugh formation and are worked near the city. The higher beds of this formation are exposed in the railroad cuts west of Wilmore, and the many beds of shale observed there indicate the presence of good brick-making material in the hills between Wilmore and Summerhill along the Pennsylvania Railroad. At the Mercer horizon also shales are associated with the coal and fire clay.

At the Bruce H. Campbell quarry, north of Sheridan, a clay that is associated with bowlders and is presumably of Pleistocene age is worked. Residual clays are so widely distributed in this region as hardly to merit detailed mention.

The clays and shales that are now worked will be described and the deposits not yet exploited will be noted, especially those that are situated near markets and lines of transportation.

JOHNSTOWN DISTRICT.

Flint clay.—So far as known flint clay occurs persistently at only one horizon in the Johnstown district. This horizon lies very close to the top of the Mahoning sandstone, and in the immediate vicinity of the city is 50 to 80 feet above the horizon of the Coke Yard coal. Though fairly well distributed in favorable localities for easy exploitation, this clay is, so far as known, worked only by the Johnstown Pressed Brick Company at their plant on a hill east of the city. A section of the rocks in the hill will show the position of this clay and its relation to the underlying coal, which is at the top of the Allegheny formation.

Section of lower part of the Conemaugh formation in hill east of Johnstown.

	Ft.	in.
Concealed, and sandstone from top of hill	91	0
Shales	10	0
Black shales	5	0
Brick-red shales	40	0
Concealed, but probably shales	25	0
Dull-olive shales, weathering reddish [a]	25	0
Olive to red shales	5	0
Dark olive-green shales, slightly gritty, with iron oxide and manganese oxide on the bedding planes [a]	13–15	0
Laminated sandstone	15	0
Shales	30	0
Concealed, but with a sandstone in its upper part	42	0
Flint clay [a]		
Shales	8	0
Ferruginous shales	10	0
Green concretionary shales	10	0
Irregularly bedded shales	5	0
Sandy shales	8	0
Massive sandstone (Mahoning)	25	0
Concealed	12	0
Coal } Upper Freeport or Coke Yard coal	3	6
Bone } Upper Freeport or Coke Yard coal		5

In Dale Borough, east of Johnstown, on the road ascending Shingle Run, 2 feet of flint clay were noted at this horizon. An old prospect hole was seen on this flint clay on the county road leading to Grandview Cemetery. On the road to Ferndale, a short distance north of the Citizens' Coal Company's Eighth Ward mine, an abundance of flinty clay débris occurs above the road near the top of the massive Mahoning sandstone. In the hill above the Baltimore and Ohio tunnel, east of Island Park, some flint clay was observed on the new county road about 40 feet above the Upper Freeport coal and near

[a] Beds worked for brick material.

the top of the Mahoning sandstone. Northwest of Johnstown, in the valley of Laurel Run, a short distance east of the old coke yard, from which the Upper Freeport coal gets its local name, this flint clay is exposed, indicating a possible continuity of the bed as far west as this point. Northwest of Johnstown, on the road ascending Pleasant Hill from the valley of the Conemaugh River, a flint clay occurs about 110 feet above the Upper Freeport coal and 10 feet below a smaller seam of coal. This latter coal may possibly be higher than the seam 70 feet above the Upper Freeport at the Baltimore and Ohio tunnel. If so, this flint clay of Pleasant Hill is higher than that previously described.

On the headwaters of Mill Creek and Dalton Run and near the south edge of the area west of Stony Creek, a fairly persistent flint clay was observed well toward the base of the Conemaugh formation. These occurrences are too far from lines of transportation to be of great economic importance at the present time.

It should be added that the occurrences noted above are largely roadside outcrops at which it is impossible to determine the exact thickness and nature of the clays. Only careful prospecting can determine these points, but the fact that one of the flint clays is being successfully used at one point is significant.

Plastic clay.—The flint clay above the Mahoning sandstone assumes a plastic phase at places in the Johnstown district. Most of the valuable plastic clay in this region, however, occurs in the Lower Productive Measures or Allegheny formation. At a few places a clay bed of workable thickness lies below the Upper Freeport coal, in connection with which it might be mined. At the Cyrus Shepard mine, leased by L. J. Mitchell, east of Franklin, 2 feet 4½ inches of fire clay were measured, but the bed may not be persistent. A clay bed which promises to be of some importance underlies the limestone below the Upper Kittanning or "C" coal seam. This clay has been developed to some extent, though so far as the writers are aware it is not now worked. According to T. T. Morrell[a] it has the following composition:

Analysis of clay near Johnstown, Pa.

Silica (SiO_2)	71.98
Alumina (Al_2O_3)	26.29
Ferric oxide (Fe_2O_3)	2.21
Magnesia (MgO)	.44
Manganese dioxide (MnO_2)	.32
	101.34

[a] Second Geol. Survey Pennsylvania, Rept. H2, p. 148.

The most valuable plastic clay in the Allegheny formation is that underlying the Miller coal seam. Many of the mines operating this coal about Johnstown produce, as well, considerable amounts of this clay. This clay bed in this district generally ranges from 3 to 6 feet in thickness, but may possibly be thicker locally. It usually underlies the lower bench of the Miller seam, from which it is separated by a few inches of shale or, in the absence of this lower bench, it occurs below the main coal itself, being separated from it by 3 to 4 inches of bone or shale. It is a light-drab clay, not very hard, of irregular fracture, greasy to the touch, and slakes on exposure to the weather. Its composition is indicated by the following analyses:

Analyses of clay underlying the Miller seam.

	1.	2.	3.	4.
Silica (SiO_2)	65.90	66.40	53.10	68.82
Alumina (Al_2O_3)	20.30	19.80	27.80	20.85
Ferric oxide (Fe_2O_3)	[a]1.60	[a]1.68	[a]3.08	2.79
Magnesia (MgO)	.66	.61	.60	.23
Lime (CaO)	.09	.10	.22	.82
Soda (Na_2O)	.34	.30	.48	....
Potash (K_2O)	2.98	3.24	3.58	....
Titanium oxide (TiO_2)	1.20	1.00	1.20	MnO_2 .66
Loss on ignition	6.50	6.40	10.20	5.83
	99.57	99.53	100.26	100.00

[a] Total iron calculated as Fe_2O_3.

1. Citizens' Coal Company's Green Hill mine, Johnstown, Pa.; E. C. Sullivan, analyst.
2. A. J. Haws & Sons (Limited) mine, near the stone bridge, Johnstown, Pa.; E. C. Sullivan, analyst.
3. Seward Coal Company's mine, Seward, Westmoreland County, Pa.; E. C. Sullivan, analyst.
4. Clay underlying the Miller seam at Johnstown; T. T. Morrell, analyst, Second Geol. Survey Pennsylvania, Rept. HHH, p. 148.

This clay is worked about Johnstown by W. J. Williams at Kernville; by the Citizens' Coal Company at Green Hill; by A. J. Haws & Sons (Limited), both at Coopersdale and near the famous stone bridge, and by Robertson & Griffin on St. Clairs Run; at each place in connection with the overlying coal. Though not always worked, this clay is present at many places in this district in workable thickness.

Nearly all the product of the Johnstown mines is used at local brick plants where it is mixed with flint clay from the Mercer horizon, shipped from South Fork and from other points. When thus mixed in proper amount it forms a suitable bond in a clay that is used in the manufacture of high-grade refractory products and bricks, for blast furnace and open-hearth work, and in making sleeves, nozzles, tuyères, and other articles that are exposed to high temperatures.

The lowest plastic clay in the Johnstown district is associated with the Mercer coal, but is not exposed in the immediate vicinity of the city. In the hills lying east of Stony Creek, south of Kring, on the Baltimore and Ohio Railroad, this horizon has been prospected and some clay and shales have been found, but they have never been worked. Flint clay was not seen at any of the old prospect pits.

North of Sheridan, at the quarry of Bruce H. Campbell, the following section was measured, showing 6 feet, or possibly more, of clay below the Mercer coal:

Section of Mercer coal and shales at Bruce H. Campbell quarry, north of Sheridan.

	Ft.	In.
Massive sandstone bowlders.		
Red clay with rounded bowlders (Pleistocene?)	5–10	0
Shales	20	0
Coal and bone	1	3
Clay	6	0
Shales	6	0

This clay has never been worked, but it is apparently of good grade.

Shales.—It has been remarked that the most important shale horizons about Johnstown are confined to the lower 300 feet of the Conemaugh formation. The section given on page 346 shows the character of the lower 400 feet of beds in this group of rocks in the hill east of the city. From about 50 feet above the top of the Coke Yard coal to the top of the hill numerous promising beds of shale are exposed. Most of the shale group lying between 165 feet and 210 feet above the Coke Yard coal is being worked by the Johnstown Pressed Brick Company into a good grade of building brick. In the hill north of the city the Cambria Steel Company has quarried shales lying 100 feet above the Coke Yard coal seam and has utilized them in connection with the overlying surface clays, in the manufacture of red building bricks of good quality.

The geological structure of the region immediately around the city is such that the beds lie fairly flat, and the lower few hundred feet of the Conemaugh formation are exposed. Sections obtained in the hills around the city and along the Pennsylvania Railroad to the west indicate that the lower part of this formation is of prevailingly shaly character, comparable with that seen in the hill to the east. It is therefore probable that a great deal of brickmaking material exists in these hills which has never been tested. Though all this shale may not be of the grade of that worked by the Johnstown Pressed Brick Company some of it probably is, and much of it may be suitable for paving brick, sewer pipe, fireproofing of various sorts, and for other rough material. All the shale in the hills about the city and to the west is fairly accessible to transportation, and cheap fuel is assured by the presence of valuable coal beds 300 feet or more below.

The lowest promising shale horizon in this district is associated with the Mercer coal. The prospect pits on the Baltimore and Ohio Railroad south of Krings station show the presence of dark shales at this horizon. At points north of Sheridan the Mercer shales are

thick, and are worked in connection with the overlying Pleistocene clays at the quarry of Bruce H. Campbell. The section measured at this quarry, given on page 349, shows 20 feet of workable shales overlying the coal. They are dark brown and drab in color, somewhat sandy and concretionary. This shale is mixed with the overlying clay, and the mixture is used in making a buff or red building brick, the color depending on the proportions of shale and clay used. The beds worked at this quarry rise abruptly toward the west at a rate that carries the Mercer horizon over the tops of the hills to the west.

SOUTH FORK DISTRICT.

Flint clay.—A band of clay that occurs in the Pottsville formation in the South Fork district has been worked at points south of the Pennsylvania Railroad from South Fork westward, beyond Mineral Point, and also at a few places north of the railroad. In this district this clay is characterized by a persistent flinty streak. This clay is present in the hills along Conemaugh River, in an area extending as far west as a point about 1 mile east of Conemaugh station. The outcrop is continuous, except where the local dips and change in direction of the river carry it below drainage. The flinty clay may not be always present between Mineral Point and Conemaugh. For example, the clay observed at this horizon in the tunnel of the old Portage Railroad is not particularly flinty in character. From Mineral Point to South Fork, however, the flinty character is persistent.

This flint clay is now worked by the Garfield Fire Clay Company, near the viaduct, and by J. H. Wickes and the South Fork Fire Brick Company, west of South Fork. The following section was measured at Mr. Wickes's mine:

Section of fire clay at J. H. Wickes's mine, South Fork.

	Ft.	In.
Heavy sandstone roof.		
Plastic clay	$3\frac{1}{2}$	
Coal		$\frac{1}{8}$–2
Flint clay	$4\frac{1}{2}$	
Sandstone.		

This clay is also worked by the Page-Reigard Mining Company near Mineral Point and at South Fork, but in July, 1904, the mine at South Fork was shut down. It is reported that the plastic clay is persistent, but that the thickness of the flint clay is variable, dwindling to 14 inches in a northeast-southwest zone. A specimen of this flint clay from the central band of the bed worked near the viaduct some years ago was analyzed by T. T. Morrell, of Johnstown, with the following results:

Analysis of flint clay from the Mercer horizon near the viaduct, Cambria County, Pa.[a]

Silica (SiO_2)	45.42
Alumina (Al_2O_3)	36.80
Ferric oxide (Fe_2O_3)	3.33
Manganese oxide (MnO_2)	.48
Magnesia (MgO)	.45
Lime (CaO)	.87
Water and organic matter	12.65
	100.00

This clay is smooth, hard, compact, light to dark gray in color, and breaks with a conchoidal fracture. It burns to a straw-yellow color. The analysis, as far as it goes, indicates a fairly high-grade material, with perhaps a little too much iron. The presence or absence of alkalies was unfortunately not determined.

The clay mined at South Fork is in part shipped to Johnstown and in part mixed with plastic clay from the Lower Kittanning seam and worked up at the local brick plant. The refractory character of some of the products of this flint clay has been tested at the plant of the Cambria Steel Company at Johnstown and they have proved highly satisfactory.

Plastic clay.—About South Fork a plastic clay has been observed at some places near the top of the Mahoning sandstone. Its position corresponds with that of the band of flint clay in the Johnstown district. In the region about South Fork it has been observed at but few places and is of doubtful value. The clay below the Upper Freeport (Lemon) coal seam is fairly thick in this region, but is not worked at present. At O. M. Stineman's mine No. 3, 2 feet 3 inches of clay were measured below this coal, which may be worked at some future time in connection with the coal. This clay is not comparable in thickness with that directly underlying the Miller coal seam, which about South Fork, as near Johnstown, is the most important plastic clay in the Allegheny formation. The plastic clay associated with the Miller coal seam is usually workable, at some places having a thickness of 6 to 8 feet, though averaging about 3 to 4 feet of workable clay of good grade. A brief note on the character of this clay will be found in the description of its occurrence in the Johnstown district, where analyses also are given. There is every reason to suppose that in this district it is of the same quality as the clay mined about Johnstown. Most of the clay product of the mines about South Fork is mined in connection with the coal and is used almost entirely at the local brick plant.

Shale.—So far as known the shales in the South Fork district have not been utilized. In the two large cuts west of the town of Wilmore, on the main line of the Pennsylvania Railroad, shale beds are exposed

[a] Second Geol. Survey Pennsylvania, vol. HH, p. 147.

that vary in position from 400 to 675 feet above the Upper Freeport coal. These beds contain many promising shales, which are found in the surrounding hills, conveniently situated with respect to transportation. Their appearance indicates that they may be adapted to the manufacture of paving brick and other materials that require only an inferior grade of clay or shale. To determine their fitness for any purpose, however, practical tests must be made. In a recent cut opposite Ehrenfeld station, along the new county road, a bed of shale 50 to 60 feet thick, lying 60 feet above the Upper Freeport coal, also appears to be promising.

BLACKLICK CREEK DISTRICT.

The South Fork of Blacklick Creek flows along the northern edge of the Johnstown quadrangle. It is joined by the North Fork a short distance west of Vintondale and then flows westward beyond the limits of the area. Deposits of flint and plastic clay are found in the adjacent hills along the creek, and although many of these are conveniently situated with respect to lines of transportation, the demand has not yet been sufficient to justify their exploitation.

Flint clay.—The flint clay in the Blacklick Creek district occurs at two horizons. The higher flint clay is found in the lower part of the Conemaugh formation above what is thought to be the equivalent of the Mahoning sandstone and a few feet below a small coal bed, possibly the Gallitzin coal. This flint clay has been observed in many places north, west, and south of Wehrum, but the rise of the beds toward the east causes a gradual increase in its distance from the valley and from transportation facilities and finally its complete absence from the hills. West of Wehrum, however, both north and south of Blacklick Creek, it occurs at many points, having the unusual thickness of 7 to 8 feet in places. It is a typical flint clay in appearance, though its content of iron oxide is apparently very high. A sample collected from a roadside exposure west of Dilltown gave the following analysis:

Partial analysis of flint clay from a natural exposure west of Dilltown.

[E. C. Sullivan, analyst.]

Silica (SiO_2)	50.3
Alumina (Al_2O_3)	21.3
Ferric oxide (Fe_2O_3)[a]	10.4
Magnesia (MgO)	0.61
Lime (CaO)	0.39
Soda (Na_2O)	0.18
Potash (K_2O)	1.14
Titanium oxide (TiO_2)	0.90
Loss on ignition	12.00
	97.22

[a] Total iron calculated as Fe_2O_3.

The percentage of fluxing materials, principally iron oxide, indicated in this analysis, is so high as to prohibit its practical use. A lower flint clay, lying a few feet below what may prove to be the Upper Freeport coal, was seen at a few places in the valley of Mardis Run, near the northwestern edge of the area. This clay may correspond with the Bolivar clay of the region to the southwest. Two feet of clay were seen at one point on the outcrop and the bed may possibly be thicker. This clay is rather remote from transportation.

Plastic clay.—The coal that is being extensively worked in the valley of Blacklick Creek is regarded as the equivalent of the Lower Kittanning, Miller, or "B" seam of the Johnstown and South Fork districts. In the Blacklick Creek district, as well as along Conemaugh River, this coal is underlain by a promising clay bed. This clay is not exploited at present, and no certain measurement of its thickness was obtained. At many of the mines 2 feet or more of promising clay were seen, comparable, in appearance at least, with that in the Johnstown district.

MISCELLANEOUS OCCURRENCES OF CLAY.

Along the western flank of Laurel Ridge, near the line of the Pennsylvania Railroad, the Miller coal seam has been opened at a few places and the clay underlying it shows in workable thickness. At the coal mine of the Johnstown Coal Company more than 2 feet of clay were seen, and near Seward, beyond the western limits of this area, 12 feet of clay occur in this same position, 6 of which are worked by the Seward Brick Company.[a]

Along the southern edge of this area, at Scalp Level and Windber, where the Miller coal seam is worked on a large scale by the Berwind-White Coal Mining Company, sandy clay was observed below the Miller coal seam at Eureka mine No. 37.

PRODUCTION.

The firms named below are engaged in the brick and clay industry in this area. In addition, coal companies mining the Miller coal seam about Johnstown and South Fork may produce small quantities of the underlying clay for use in the local brick plants.

Clay miners.

Page-Reigard Mining Company, flint clay, Mineral Point.
W. J. Williams, plastic clay, Kernville.
Citizens' Coal Company, plastic clay, Green Hill mine, Johnstown.
Robertson & Griffith, plastic clay, St. Clairs Run, Morrellville.

[a] For an analysis of the clay underlying the coal mined at Seward, see p. 348.

Manufacturers of fire brick.

Harbison-Walker Company, Cambria City.
A. J. Haws & Sons (Limited), Johnstown and Coopersdale.
Hiram Swank Sons, Johnstown.
South Fork Fire Brick Company, South Fork.

Manufacturers of building brick.

Cambria Steel Company, Johnstown.
Bruce H. Campbell Brick Company, Sheridan.
Johnstown Pressed Brick Company, Johnstown.

The following table gives a fair idea of the value of the brick industry in this region during the past two years:

Quantities and values of clay products in region about Johnstown, Pa., in 1904 and 1905.

	1904.		1905.	
	Amount.	Value.	Amount.	Value.
Building brick, including red and fancy-colored varieties	6,946,000	$50,772	12,549,000	$88,444
Fire brick, including refractory block and tile	26,024,000	482,647	33,648,000	600,798
	32,970,000	533,419	46,197,000	689,242

SURVEY PUBLICATIONS ON CLAYS, FULLER'S EARTH, ETC.

Ina ddition to the papers listed below, references to clays will be found in the publications listed under the head of "Cements," on pages 245–246.

ASHLEY, G. H. Notes on clays and shales in central Pennsylvania. In Bulletin No. 285, pp. 442–444. 1906.

BASTIN, E. S. Clays of the Penobscot Bay region, Maine. In Bulletin No. 285, pp. 428–431. 1906.

BRANNER, J. C. Bibliography of clays and the ceramic arts. Bulletin No. 143. 114 pp. 1896.

CRIDER, A. F. Clays of western Kentucky and Tennessee. In Bulletin No. 285, pp. 417–427. 1906.

ECKEL, E. C. Stoneware and brick clays of western Tennessee and northwestern Mississippi. In Bulletin No. 213, pp. 382–391. 1903.

——— Clays of Garland County, Ark. In Bulletin No. 285, pp. 407–411. 1906.

FISHER, C. A. The bentonite deposits of Wyoming. In Bulletin No. 260, pp. 559–563. 1905.

FULLER, M. L. Clays of Cape Cod, Massachusetts. In Bulletin No. 285, pp. 432–441. 1906.

GOLDING, W. Flint and feldspar. In Seventeenth Ann. Rept., pt. 3, pp. 838–841. 1896.

HILL, R. T. Clay materials of the United States. In Mineral Resources U. S. for 1891, pp. 474–528. 1892.

——— Clay materials of the United States. In Mineral Resources U. S. for 1892, pp. 712–738. 1893.

LANDES, H. The clay deposits of Washington. In Bulletin No. 260, pp. 550–558. 1905.

PHALEN, W. C. Clay resources of northeastern Kentucky. In Bulletin No. 285, pp. 412–416. 1906.

RIES, H. Technology of the clay industry. In Sixteenth Ann. Rept., pt. 4, pp. 523–575. 1895.

——— The pottery industry of the United States. In Seventeenth Ann. Rept., pt. 3, pp. 842–880. 1896.

——— The clays of the United States east of the Mississippi River. Professional Paper No. 11, 298 pp. 1903.

SCHRADER, F. C., and HAWORTH, E. Clay industries of the Independence quadrangle, Kansas. In Bulletin No. 260, pp. 546–549. 1905.

SHALER, N. S., WOODWORTH, J. B., and MARBUT, C. F. The glacial brick clays of Rhode Island and southeastern Massachusetts. In Seventeenth Ann. Rept., pt. 1, pp. 957–1004. 1896.

SIEBENTHAL, C. E. Bentonite of the Laramie basin, Wyoming. In Bulletin No. 285, pp. 445–447. 1906.

VAUGHAN, T. W. Fuller's earth deposits of Florida and Georgia. In Bulletin No. 213, pp. 392–399. 1903.

WILBER, F. A. Clays of the United States. In Mineral Resources U. S. for 1882, pp. 465–475. 1883.

——— Clays of the United States. In Mineral Resources U. S. for 1883–84, pp. 676, 711. 1885.

WOOLSEY, L. H. Clays of the Ohio Valley in Pennsylvania. In Bulletin No. 225, pp. 463–480. 1904.

BUILDING STONE AND ROAD METAL.

RECENT WORK ON NEW ENGLAND GRANITES.

By T. Nelson Dale.

AREA CONSIDERED.

During the summer of 1905 the writer visited all the important granite quarries in Maine, and in 1906 all those at the chief granite centers of New Hampshire, Massachusetts, and Rhode Island, namely, Concord, Conway, and Milford, in New Hampshire; Milford, Quincy, and Rockport, in Massachusetts, and Westerly and Niantic in Rhode Island. The quarry at Chester, Mass., was also visited. The State of Maine cooperated with this Survey in bearing the expense of the work in its territory, but the work in the other States was done entirely at the expense of the United States Geological Survey.

WORK IN MAINE.

The results of the Maine work are soon to be presented in a bulletin entitled "The granites of Maine," to which Dr. George Otis Smith has contributed an introductory chapter and map showing the geographic and general geologic relations of the granites in that State. The bulletin will also include the statistics of granite production in Maine for 1905, prepared by Miss A. T. Coons.

A brief outline of this forthcoming report on the Maine quarries may be of interest to persons engaged in the granite industry.

The number of quarries and prospects visited, including those of "black granite" for monumental use, amounted to 129. The capital invested in the entire Maine granite industry in 1905 amounted to about $3,500,000. This estimate is based upon fair valuations of the quarries themselves, of the plants, and of the amount of "working capital" that is required to carry on the present business.

The report is designed to be helpful to those who are engaged in quarrying and working granite, as well as to architects, contractors, and dealers in monumental stone, and it will also make known to geologists

the results of such scientific observations as were made in the course of the work. In order to accomplish these various purposes it has been divided into two parts—a scientific and an economic part. The first is practically a brief text-book on granite in general, illustrated by the granite quarries of Maine and written as far as has been possible in untechnical language, so as to be intelligible to working and business men. This part treats of the origin, mineralogical and chemical composition, texture, structure, physical properties, and classification of granite and "black granites." Under the heading "Structure" the nature and origin of sheets, rift, grain, flow structure, joints, headings, and faults are considered. Dikes, veins, "knots" (segregations), geodes, inclusions, and contacts are described and discussed, as well as the discoloration and decomposition of granite.

In the economic part the various tests of granite, the adaptation of the stone to different uses, and the methods of granite quarrying are first considered. An economic classification of Maine granites based upon visual characteristics is next given, and next follow the descriptions of the quarries and their products, the matter here being arranged by counties in alphabetic order. These descriptions follow a uniform method, taking up, in succession, (1) the name and location of quarry, name and address of operator and superintendent; (2) the granite, including its description in the rough and under the microscope, together with the results of any tests and analyses; (3) the quarry, its dimensions, drainage, and water supply; (4) the stripping and rock structure; (5) the plant, including an enumeration of all machines and pneumatic tools, to show its capacity; (6) the means of transportation; (7) labor, both of men and animals; (8) product, its uses and market, together with the names and location of a few buildings or monuments in whose construction the stone has been used.

At the end of the report is a bibliography on the economic geology of granite and a glossary of such scientific terms as were unavoidably used and also of current quarry terms. The report includes 14 plates illustrating various features of scientific or economic interest in the quarries or their product and 39 text figures. Most of these text figures are diagrams showing the course of joints, headings, and dikes at the quarries, but others illustrate "rift," sheet structure, "sap," or the use of explosives, or show the location of individual quarries at the industrial centers. The situation of these centers is indicated by symbols on the geological map.

WORK IN OTHER STATES.

A report on the granite quarries of New Hampshire, Massachusetts, and Rhode Island will follow the plan of the economic part of that on Maine granites, but will include such supplementary matter of scientific interest as has been collected in the course of the work.

Eighty-eight quarries were visited. The granite of nearly all of these quarries differs from that of those in Maine, and some of the geological features of the quarries are also different. These granites differ also greatly among themselves, as may be seen by noting the various kinds produced. Among these are the fine-grained Westerly granites, so well adapted to the most delicate sculpture, and the Milford, N. H., and Chester, Mass., granites, which somewhat resemble them; the dark hornblende-augite monumental granite of Quincy, Mass., noted for its high polish; the massive structural granite of Milford, Mass., which is going into several important public structures; the medium-grained light-gray muscovite granite of Concord, N. H., used in the Congressional Library at Washington; the olive-colored granites of Rockport, Mass., and Redstone, N. H.; the pink granite of Redstone, N. H., and the mottled medium-gray granite of Rockport, Mass.

In describing these stones polished specimens of one or two typical granites from each district will be examined by the Rosiwal method, and the estimated percentages of the chief mineral constituents will be given in connection with the microscopic descriptions. Some of these estimates have already been completed, and are presented below in advance.

The "extra dark" hornblende-augite granite of the J. S. Swingle quarry at West Quincy, Mass., shows feldspar, 56; hornblende-augite, 10.50; smoky quartz, 33.50.

The "dark" granite of the Granite Railway Company's quarry at the same place shows feldspar, 58.79; hornblende-augite, 7.47; smoky quartz, 33.74.

The "dark" granite of the Maguire & O'Heron quarry at Milton, near Quincy, shows feldspar, 55.80; hornblende-augite, 11.10; smoky quartz, 33.10.

The "medium" granite of the Wigwam quarry of Badger Brothers at West Quincy shows feldspar, 69.51; hornblende-augite, 8.43; smoky quartz, 22.06.

These results indicate that the difference in the shade of Quincy granites, designated commercially by "medium," "dark," and "extra dark," is due partly to differences in the percentage of the hornblende-augite and partly to differences in that of the smoky quartz.

The medium gray granite from the Pigeon Hill quarry (Lower quarry) of the Pigeon Hill Granite Company at Rockport, on Cape Ann, Mass., shows feldspar, 58.86; hornblende, 7.26; smoky quartz, 33.88.

In examining the fine-grained granites the Rosiwal method is applied to camera lucida drawings made from thin sections, with an enlargement, in the finest ones, of 40 diameters. The finest of the

Westerly granites, the "white granite" of the New England Granite Works, which is really a medium pinkish gray, shows when thus examined feldspar, 59; black mica, 3.85; very slightly smoky quartz, 36; magnetic iron, 0.75; white mica, 0.50. It also shows that the average diameter of all the particles, including the very fine particles of magnetic iron, is 0.0069 inch, or 0.175 millimeter; but the coarser particles of feldspar, quartz, and mica as measured with the micrometer range in diameter from 0.015 to 0.439 inch, or 0.39 to 1.122 millimeters.

The study of the numerous economic and scientific data obtained at all these quarries is not sufficiently advanced to permit any further preliminary publication.

The two reports together will, it is hoped, constitute an important contribution to an authoritative compend of the economic geology of New England granites.

SURVEY PUBLICATIONS ON BUILDING STONE AND ROAD METAL.

The following list comprises the more important publications on building stone and road metal by the United States Geological Survey:

ALDEN, W. C. The stone industry in the vicinity of Chicago, Ill. In Bulletin No. 213, pp. 357–360. 1903.

BAIN, H. F. Notes on Iowa building stones. In Sixteenth Ann. Rept., pt. 4, pp. 500–503. 1895.

DALE, T. N. The slate belt of eastern New York and western Vermont. In Nineteenth Ann. Rept., pt. 3, pp. 153–200. 1899.

——— The slate industry of Slatington, Pa., and Martinsburg, W. Va. In Bulletin No. 213, pp. 361–364. 1903.

——— Notes on Arkansas roofing slates. In Bulletin No. 225, pp. 414–416. 1904.

——— Slate investigations during 1904. In Bulletin No. 260, pp. 486–488. 1905.

——— Note on a new variety of Maine slate. In Bulletin No. 285, pp. 449–450. 1906.

DALE, T. N., and others. Slate deposits and slate industry of the United States. In Bulletin No. 275. 1906.

DILLER, J. S. Limestone of the Redding district, California. In Bulletin No. 213, p. 365. 1903.

ECKEL, E. C. Slate deposits of California and Utah. In Bulletin No. 225, pp. 417–422. 1904.

HILLEBRAND, W. F. Chemical notes on the composition of the roofing slates of eastern New York and western Vermont. In Nineteenth Ann. Rept., pt. 3, pp. 301–305. 1899.

HOPKINS, T. C. The sandstones of western Indiana. In Seventeenth Ann. Rept., pt. 3, pp. 780–787. 1896.

——— Brownstones of Pennsylvania. In Eighteenth Ann. Rept., pt. 5, pp. 1025–1043. 1897.

HOPKINS, T. C., and SIEBENTHAL, C. E. The Bedford oolitic limestone of Indiana. In Eighteenth Ann. Rept., pt. 5, pp. 1050–1057. 1897.

KEITH, A. Tennessee marbles. In Bulletin No. 213, pp. 366–370. 1903.

RIES, H. The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut. In Seventeenth Ann. Rept., pt. 3, pp. 795–811. 1896.

SHALER, N. S. Preliminary report on the geology of the common roads of the United States. In Fifteenth Ann. Rept., pp. 259–306. 1895.

——— The geology of the road-building stones of Massachusetts, with some consideration of similar materials from other parts of the United States. In Sixteenth Ann. Rept., pt. 2, pp. 277–341. 1895.

SIEBENTHAL, C. E. The Bedford oolitic limestone [Indiana]. In Nineteenth Ann. Rept., pt. 6, pp. 292–296. 1898.

SMITH, G. O. The granite industry of the Penobscot Bay district, Maine. In Bulletin No. 260, pp. 489–492. 1905.

GLASS-MAKING MATERIALS.

GLASS-SAND INDUSTRY OF INDIANA, KENTUCKY, AND OHIO.

By Ernest F. Burchard.

LOCAL GLASS-MAKING INDUSTRY.

Of the States manufacturing glass, Indiana and Ohio at present occupy, respectively, second and third rank. The total value of their glass products amounted in 1905 to $23,733,137, which is nearly one-third of the total value of the glass made in the United States. As the glass industry is largely dependent for its raw materials on the mineral deposits sand and limestone, the investigation of these materials for glass making, begun in 1905 in the Mississippi Valley, was resumed in December, 1906, in the Ohio Valley. It is of interest to note the sources of these materials, to compare their costs with that of other materials and with that of the finished product, and to consider whether any economies can be effected in their production. The following table shows the principal materials used in the manufacture of glass, their quantity and cost, and the character and value of the products in Indiana and Ohio for 1905.[a]

Glass-making materials used by kind, quantity, and cost, and products, by kind and value; Indiana and Ohio, 1905.

	Indiana.		Ohio.	
	Quantity.	Cost.	Quantity.	Cost.
Materials used, total cost		$5,558,839		$2,836,521
Glass sand ... tons	193,600	316,265	81,541	179,152
Limestone ... tons	27,120	54,055	11,704	21,562
Lime ... cwt	170,433	50,492	104,321	21,281
Soda ash (carbonate of soda) ... tons	55,249	1,039,241	19,683	372,630
Salt cake (sulphate of soda) ... tons	9,963	157,341	5,547	87,946
Nitrate of soda ... tons	2,156	98,861	1,376	59,146
Litharge (red lead) ... lbs	790,509	41,106	2,441,307	140,837
Potash or pearlash ... lbs	435,100	19,181	1,331,355	57,826
Pots, not made at factory ... No	1,589	67,263	1,070	71,980
Lumber, casks, barrels, boxes, and nails		1,231,220		623,406
Caps, metal trimmings, and rubber supplies		712,312		110,475
Fuel and rent of power and heat		1,069,075		621,497
All other supplies and materials		702,427		454,404
Products, total value		14,706,929		9,026,208
Building glass		3,790,618		1,625,126
Pressed and blown glass		2,859,087		3,954,660
Bottles and jars		7,213,456		2,961,727
All other products		843,768		484,695

[a] Census of Manufactures, clay and glass products, 1905: Bulletin U. S. Bureau of the Census No. 64, 1906.

In Indiana 71 glass works are in business, this number including 16 temporarily not in operation. Of these 71 plants, 39 make general flintware, 17 window glass, 3 plate glass, and 3 cast and rolled glass, including cathedral, colored, and opalescent glass; 9 confine their product to green and amber bottles, and some green and amber ware is also made by the flint factories.[a]

The glass works are situated mainly in the gas belt and coal fields of the State. With the gradual lessening of the natural-gas supplies during the last five years, the growth of the industry in Indiana has received a check. Many factories have been moved to Kansas and others have been moved from the gas fields to points within the State where cheap coal can be obtained. The introduction of glass-blowing machinery has, to some extent, offset the increased cost of fuel by reducing the number of employees and enlarging the output of the works, but the net result has been a slight loss in the total value of products since 1900.

In Ohio there are 50 glass works, one of which is temporarily inactive. Of these, 25 make general flintware; 16 window glass, 1 plate glass, and 2 cast and rolled glass.[a]

The glass-making industry in Ohio is in a prosperous condition. From 1900 to 1905 the value of products increased 98.5 per cent, and the amount paid in wages increased 118.2 per cent.

PRODUCTION OF GLASS SAND.

The following table shows the relation of production and value of glass sands produced in Indiana and Ohio to the total consumption of the material in these States.

Glass sand produced and consumed in Indiana and Ohio in 1905.[b]

State.	Production.			Consumption.			Production proportioned to consumption.
	Quantity.	Value.		Quantity.	Cost.		
	Short tons.	Total.	Average per ton.	Short tons.	Total.	Average per ton.	Per cent.
Indiana	1,640	$2,169	$1.32	193,600	$316,265	$1.63	0.84
Ohio	76,460	79,999	1.05	81,541	179,157	2.20	93.76

From these figures it is apparent that Indiana is producing less than 1 per cent of the glass sand used within the State; also that the sand produced can be sold for about 81 per cent of the average price paid for imported sand. This is a perfectly natural condition, since the local sand has the advantage of a differential in freight rates of 50

[a] Courtesy of The Commoner Publishing Company, Pittsburg, Pa., January, 1907.

[b] Statistics of production by A. T. Coons: Production of glass sand in 1905; Mineral Resources U. S. for 1905, U. S. Geol. Survey, 1906.

cents per ton over the sand brought from the Fox River (Illinois) district and the Klondike (Missouri) district. All the sand that can be produced, of sufficient purity even for green and amber bottles, finds a ready and waiting market at good prices. These conditions are encouraging to producers and manufacturers alike, and there is a tendency now on the part of certain manufacturers to secure for themselves reserves of undeveloped sandstone. At the same time it must be remembered that no large quantities of sandstone are known in Indiana which have the purity of the St. Peter sandstone, so abundant farther west. Consequently, for certain grades of glass, there will always be a demand for sand from beyond the State. As to the quantities of crushed limestone and burned lime produced within the State, there are at present no definite statistics, but the procuring of these materials does not seem to offer any serious difficulties, first, because much smaller quantities of them are used than of sand; second, because certain quarries in Illinois and Ohio have a well-established trade, and third, because Indiana herself has, in the Mitchell and Bedford limestones, inexhaustible supplies of satisfactory material.

According to statistics, Ohio produced 93.7 per cent as much glass sand as is used in the State. A large part of this product, however, passes from the eastern part of the State to glass factories in western Pennsylvania, and a corresponding amount is brought in from other States—notably from West Virginia and Illinois—at relatively higher prices. Glass works are established within an area extending north and south across the State from Toledo to Cincinnati and as far east as Steubenville. Each plant is usually well situated with regard to fuel, either natural gas or coal, but many have to pay excessive freight charges on their sand. The opening of new deposits and the readjustment of markets would simplify this situation.

Kentucky has only recently begun to manufacture glass. Factories are in operation at Frankfort and Owensboro, and glass sand is produced at Tip Top.

PREPARATION OF GLASS SAND.

The method of treatment of glass sand depends on the character of the deposit and on its position. The materials used for glass sand in central United States are mainly bedded sandstones, and a complete process of preparation includes quarrying, breaking, crushing, and grinding into component grains, screening, washing, draining, drying, and final screening to various sizes. Some beds of sandstones are so loose and friable that they can be reduced by a strong hydraulic jet; some producers dispense with the operation of washing their sand, others do not dry it. It has been shown that washing improves the quality of sand of the highest grade.[a] It is mistaken economy to neglect this important

[a] Burchard, E. F., Glass sand of middle Mississippi basin: Bull. U. S. Geol. Survey No. 285, 1906, p. 461.

phase of treatment on account of the expense of installing washers, for the price of sand, and often its use or rejection, is affected by the small percentage of impurity that may be washed away. Two methods of washing are followed. One method involves several sets of bins, into which sand and water are elevated or pumped so that the sand settles quickly while the finer impurities are washed away; the other employs a crude, open-top pug mill, in which rotating "augers" or screws move the sand up inclined troughs, rolling it over and over so that by attrition it is freed from a large portion of its impurities and stain, and the impurities are then readily removed by a stream of water playing down the troughs.

Drying is effected by three general types of apparatus: (1) Rotary cylinders, through which the sand passes against a draft of flame and hot gas; (2) a stationary roaster, and (3) coils of steam pipes. The first method involves the greatest initial cost, but is by far the most rapid and efficient. Fuller description of methods of obtaining and preparing sand will be found under the heading "Detailed descriptions of sand properties," pp. 367-375.

Sand that passes a 60-mesh sieve or one of smaller mesh is regarded as fine grained; that which passes 30- and 40-mesh sieves is regarded as medium grained, and that which is retained by 30- or 20-mesh sieves or sieves of coarser mesh is considered coarse grained. These divisions have been made the basis for classifying, according to their grain, the various sands mentioned in the following notes.

ROCKS UTILIZED.

INDIANA AND KENTUCKY.

In Indiana sandstones of Silurian, Devonian, Carboniferous, and Tertiary age have been utilized for glass making, but at present the Carboniferous sandstone furnishes the greater part of the glass-sand output.

Silurian.—Rocks of Niagara age extend from the Illinois line, in Newton County, eastward nearly across Indiana and cover the upper Wabash Valley. For the most part they are buried under a great thickness of drift. These Niagara rocks consist principally of magnesian limestone of varying composition and texture, but in some localities they occur as thin lenses of sandstone. One of these lenses, near Kenneth, Cass County, 3 miles west of Logansport, is 5½ feet thick and is composed of pure white quartz sand, containing only traces of calcium carbonate and iron. Just west of the Hamilton-Madison county line, at a point 1½ miles southwest of Fishersburg, a 5-foot bed of very pure white sandstone has been quarried for glass making. At this point the rock is massive, fine grained, and friable, and is overlain by less than 1 foot of buff magnesian limestone, over

which lie 18 to 24 inches of surface clay. Owing to the scarcity of outcrops and the thinness of the beds the sandstone of the Niagara formation can hardly be regarded at present as a very valuable source of glass sand in this region.

Devonian.—Rocks of Devonian age, like those of Silurian age, are covered by thick drift where they occur in the northern part of Indiana, but farther south are more favorably situated. In the vicinity of Pendleton, 28 miles northeast of Indianapolis, there is a massive, soft, white sandstone, varying in thickness from 7 to 15 feet. This sandstone is sufficiently pure for use as a glass sand and has been quarried as such at Pendleton, but in general has not proved thick enough for successful exploitation.

Carboniferous.—Sandstone and shale of Pennsylvanian age constitute the country rock of the southwest part of Indiana from Ohio River northward to Benton County, for a distance of 200 miles, in which they outcrop to a width varying from 2 to 3 miles at the north and reaching 75 miles at the south. These rocks dip westward, or a little south of west, so gently that locally they are nearly horizontal. Active quarries at Wolcott, White County; Loogootee, Martin County, and Coxville, Parke County, are in Pennsylvanian rocks, the first two being in the Mansfield sandstone.

The Mansfield sandstone, or "Millstone grit," the basal conglomeratic sandstone of the Pennsylvanian series, doubtless is more important to the glass-sand industry than any other formation in the State. It varies greatly in texture, color, and thickness. Locally it is a coarse conglomerate, which grades into a coarse sandstone, and in places it consists of alternating sandy and pebbly strata. The sandstone may be massive or thin bedded, and at many places it shows cross-bedding. The rock is mostly rather friable, but along bedding planes, in places where it is cemented by ferric oxide, it becomes very hard. It comprises hollow nodular masses and thin streaks of limonite and thin streaks of carbonaceous matter in all stages of alteration, from decomposed woody matter to bituminous coal, and these are accompanied by seams of fire clay. The color of the rock, where freshly broken, ranges from white and light gray, through buff, yellow, and brown, to red. The outcrop area of the formation is about 12 miles wide from west to east in Martin County, where the rock is well exposed by the drainage system of East Fork of White River. The beds strike in general N. 12° W., and a strip running 15 miles wide extends in Indiana from Ohio River at Canneltown, Perry County, for about 180 miles north-northwest into Benton County, where it becomes hidden by consolidated gravels, clays, and soils of Quaternary age. The Mansfield sandstone occurs in Benton, Jasper, Owen, Monroe, Greene, Lawrence, Martin, Daviess, Orange. Dubois, Crawford, Perry, and Spencer counties. Owing to

its superior durability, it has expressed itself strongly on the topography, forming vertical cliffs and capping many limestone and shale hills. Its observed thickness ranges from a few feet to more than 100 feet, although 40 to 60 feet are the usual limits. In consequence of its position above ground-water level it is at most places well situated for quarrying and is also well situated as regards transportation facilities, since no less than 16 railroad lines cross its area of outcrop in Indiana.

A Pennsylvanian sandstone of later age than the Mansfield is worked extensively for glass sand at Coxville, Parke County. The geologists of the Indiana survey regard this rock as the filling of a valley or channel carved in the "Upper Coal Measures." It appears to be younger than coal "VI" and older than coal "VII," and may correspond to the Merom sandstone of Sullivan County. Other evidences of filled channels have been observed in Parke and Fountain counties, and in Vermilion County, Ill., and these channels have been tentatively referred to the drainage system of the "Coxville Carboniferous River."[a]

Tertiary(?).—Deposits of sand, gravel, and, in places, conglomerate occur on the high points of the upland bordering the Ohio River flood plain in Indiana and Kentucky. G. H. Ashley[b] mentions their occurrence in Spencer, Perry, Harrison, Washington, Floyd, and Clark counties, Ind., and the writer has observed deposits of a similar nature in Hardin County, Ky. As these fragmentary deposits are associated with an old peneplain and are evidently younger than Carboniferous and older than Quaternary, they are regarded by Ashley as of Tertiary age. These beds, known as the Ohio River formation, consist of white, yellow, red, and brown sand and soft sandstone, which farther south attain a thickness in places of more than 50 feet. The grain of the material grows coarser from south to north, and the thickness of the deposits decreases notably toward the north. Beds of various-colored clays are found at or near the bottom of the deposits. Sands of the Ohio River formation have been dug for glass material at De Pauw and New Albany, Ind., and are now being exploited at Tip Top, Ky.

Maps and publications.—The United States Geological Survey has not yet issued topographic or geologic maps of these areas, but the Indiana Geological Survey has thoroughly covered the ground in that State, and much information may be obtained concerning the sandstones from the twentieth, twenty-first, twenty-third, and twenty-eighth annual reports of the Indiana survey, the latter containing a State geological map.

[a] Ashley, G. H., The coal deposits of Indiana: Twenty-third Ann. Rept. Dept. Geology and Natural Resources Indiana, Indianapolis, 1898, pp. 80, 300, 345, 378, 385, 386, and 406.

[b] Ashley, G. H., and Kindle, E. M., The geology of the Lower Carboniferous area of southern Indiana: Twenty-seventh Ann. Rept. Dept. Geology and Natural Resources Indiana, Indianapolis, 1903, pp. 68–70.

OHIO.

Sandstones of Silurian and Carboniferous age are at present being exploited for glass sand in Ohio.

Silurian.—Interbedded with the "Lower Helderberg" ("Waterlime") limestones are a few beds of extremely pure silica sandstone that have long been known to outcrop in northwest Ohio, in Lucas and Wood counties, and in Monroe County, Mich. These beds have been grouped together as the Monroe formation by the Michigan Geological Survey.[a]

The quarries at Sylvania and Holland, Ohio, are in this sandstone. Silurian limestones occupy fully one-third of the area of the State and contain lenses of sandstone at some places, as in Champaign and Logan counties.

Carboniferous.—Sandstones covering a wider range in geological position than those available in the Silurian occur in the Carboniferous system in Ohio. The lowest beds utilized are formations of the Waverly group of the Mississippian series, locally termed the Black Hand formation, which is worked at Black Hand on Muskingum River, below Newark. Other localities in which Mississippian sandstones are worked are at Rockbridge, Hocking County, and at Akron.

Rocks of early Pennsylvanian age, belonging to the "Conglomerate" group, or Pottsville formation, are widespread and are worked for glass sand at Chalfants and Niles. Sandstone still higher in the system, or in the "Lower Coal Measures," is another source of glass sand. Such is the Massillon sandstone, quarried at the city of that name. Topographic maps of the Akron, Massillon, and Toledo quadrangles are issued by the United States Geological Survey, and the Ohio Geological Survey has issued a number of geologic maps showing, in a general way, the distribution of the rock formations in this State. Among the most useful of these are the atlases accompanying Volumes V, VI, and VII, as well as a small-scale map in Volume VIII and the large atlas sheets issued in 1879.

DETAILED DESCRIPTIONS OF SAND PROPERTIES.

INDIANA.

Coxville.—The works of the Acme Glass Sand Company are located at Coxville, about 2 miles northwest of Rosedale, a station on the Vandalia line, 16 miles northeast of Terre Haute. The sandstone quarried here is a deposit filling an erosion channel in the "Productive Coal Measures." The sandstone is exposed to a height of about 40 feet above the flood plain of Raccoon Creek. The base of the deposit is not exposed in the quarry, but overlies shale and coal "No. VI" at the margins of the channel, which are some 600 feet apart.

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[a] Lane, A. C., Rept. State Board of Geol. Survey for 1891-92, Lansing, Mich., 1893, p. 66.

The beds are massive, lie nearly horizontal, and are covered by a few inches to nearly 10 feet of drift clay containing bowlders and gravel. This sand is rather soft, of medium-sized, angular grains, and the mass ranges from white to light brown in color. Close inspection shows that certain beds are speckled with iron-oxide spots the size of a pin head, so closely spaced that 30 or more spots appear in a square inch of surface. The sand is slightly micaceous and the bed contains occasional clay streaks. When crushed and dried the average sand has a light yellowish-brown color, due to impurities, a large proportion of which might be removed if the product were washed. The process of treatment is simple. After the customary drilling and shooting down, the broken rock and loose sand is loaded into the mill by a steel bucket on a cable conveyer and dumped directly into a Blake jaw crusher. The material then passes through one set each of corrugated rolls and smooth rolls and is thus separated into its individual grains. A belt conveyer, elevator, and chute, in the order given, carry the sand to a rotary drier burning coke. From the drier the sand may be delivered directly to cars or stored in bins. The capacity of this mill is about 250 tons a day. The quarry is fairly well situated with respect to transportation facilities, having direct connections with the Chicago and Eastern Illinois Railroad, and switching connections at Rosedale with the Vandalia line. The market for this sand consists chiefly of glass works in the State that make beer bottles. Some of these works are at Terre Haute. Without washing the sand is not satisfactory for flint and window glass. It is, however, in great demand for furnace use. Its analysis is shown on page 376.

Loogootee. The Loogootee Glass Sand Company operates a quarry in Martin County, 1½ miles east of Loogootee, on the Baltimore and Ohio Southwestern Railroad. The Mansfield sandstone occurs in this vicinity in its typical development, forming the bluff of Boggs Creek, about 50 feet high, and it is reported to be nearly 100 feet thick, as determined by drill. A face of 25 feet above the railroad level is open in the quarry, disclosing masses of cross-bedded white to brown, rather coarse, soft sandstone containing a thin bed of fine quartz pebbles. Thin lenses of dark iron-cemented sandstone are common and in places iron oxide has been segregated to such an extent as to form lenses 1 foot thick. Streaks of carbonaceous matter further increase the percentage of impurity in the deposit, while joint planes enlarged to a width of 6 inches are filled with clay from the surface. All these objectionable substances, constituting about 5 per cent of the quarried material, are separated by hand.

The equipment of this plant is at present inadequate, but the addition of more complete washers, together with driers, is contemplated. From the quarry the material is wheeled in barrows into a small mill consisting of one set of rolls, a rotary screen having 10 meshes to the

inch, and 2 wash bins. A belt conveyer delivers the sand into cars on a siding. The present capacity of this plant is 150 to 200 tons weekly. The best grade of sand is used at Loogootee for common bottles and fruit jars. Other grades are used for molding, and some goes to the large lime quarries at Mitchell and Bedford for stone sawing. The quartz pebbles, separated by screening, are reserved for sale separately.

Wolcott.—The quarry at Wolcott, formerly operated by the American Window Glass Company, was not visited by the writer, but E. M. Kindle has made mention of it as follows:[a]

> Just west of Wolcott the Mansfield sandstone appears at the surface. It is extensively quarried for glass making in the southwest quarter of section 25. The section exposed in the quarry shows:

	Ft.	in.
Surface clay	6	8
Light bluish gray, coarse sandstone with quartz pebbles scattered through it	25	

> The sandstone is very friable and in part of the quarry is but little more than an unconsolidated sand.

KENTUCKY.

Tip Top.—The Kentucky Silica Company has opened recently a sandpit at Tip Top, Hardin County, 28 miles southwest of Louisville, on the Illinois Central Railroad. Post-Carboniferous sand, probably of Tertiary age, is obtained here from a deposit occupying the highest points of the upland surface and reaching elevations of 400 feet above the mean level of Ohio River. As stated on page 366, this sand is probably to be correlated with the Ohio River formation of the Indiana geologists. It here attains a thickness of more than 50 feet and covers 40 or more acres. The deposit consists of massive sandstone, so soft and so poorly cemented that it crumbles when touched. The sand is mainly white and yellow, the yellow sand constituting the upper three-fifths of the deposit. Along joints the yellow sand has been stained deep red by infiltration of a fine red silt from the surface. The lowest beds exposed in the quarry are of pure white, very fine-grained, clear quartz sand, and interstratified with them are a few lenses and bands, 2 to 6 inches thick, of yellow and white plastic clay. At the lowest point excavated in the quarry a reef of fossiliferous chert has been uncovered, but this was not visible at the time of the visit. Deep drill holes within one-half mile of the deposit do not encounter any such beds as are here exposed and thus tend to confirm the belief as to the fragmentary nature of the deposit. The acreage of sand available, however, has proved to be large enough to warrant the erection of an efficient plant for procuring and washing the product.

[a] Kindle, E. M., Stratigraphy and paleontology of the Niagara in northern Indiana: Twenty-eighth Ann. Report Dept. Geology and Natural Resources Indiana, Indianapolis, 1904, p. 417.

The hydraulic method, so successfully used in the Ottawa, Ill., glass-sand district, is employed here to remove the sand from the pit. The material is so slightly indurated that a jet of water from the nozzle of a large hose is sufficient to break it down, free it from the interbedded clay, and wash it into the sump of a Nye pump at the lowest point in the pit. The pump raises the sand about 12 feet to a screen having one-eighth inch meshes. The screened sand drops through the chute into a tank, from which it is carried by a gently inclined elevator out of the pit into the first set of wash bins. The washers consist of 2 sets of 2 bins each, the bins of the first set holding about 25 tons each, those of the second holding about 40 tons each. A second elevator carries the sand to the second set of bins, from which a second Nye pump moves the sand to the drain bins. The sand is not subjected to any further drying. The drain bins are used for storage purposes and are built alongside a railroad spur. They consist of 3 bins of 50 tons capacity each and 3 of 40 tons each, making convenient measures in loading cars. They are built of 2 by 6 inch lumber, laid flat, and have a basal compartment 8 feet deep, filled with cinders to insure rapid drying. Owing to the upland location of this quarry water is scarce, and the problem of maintaining a steady and adequate water supply has been solved satisfactorily by utilizing the waste waters from the washers after thorough settling, the loss from evaporation and seepage being replenished by piping a supply down from a pond about one-third of a mile distant. The dissected topography has favored the construction of storage and settling bins. The present capacity of this plant is about 200 tons a day, and it is planned to install steam driers in order to increase this capacity and to furnish the sand in better condition. The white and yellow sands are worked up together, and after washing make a light-colored, clean quartz sand, suitable for good grades of glass. When prepared by itself the white sand is of very high grade, while the deep red clay sand makes an excellent molding material. The glass sand is mostly used at present by the flint and bottle houses at Frankfort, Ky. Analyses of this sand are given on page 376.

OHIO.

Sylvania.—The plant of the Toledo Stone and Glass Sand Company is located about 4 miles southwest of Sylvania, a station on the Lake Shore and Michigan Southern Railway, 10 miles northwest of Toledo. Sandstone and dolomite are obtained in neighboring quarries from beds of the Monroe formation. In the latest Ohio Survey reports the sandstone phase is termed the Sylvania sand-

stone, and the limestone phase the Lucas limestone. The rocks are covered by only a thin veneer of drift, a few inches to 2 or 3 feet thick. The surface of the country is flat and the rocks are quarried from two large pits trending north-south, or with the strike of the rocks. The beds dip about 5° to the west, the sandstone underlying the dolomite and outcropping on the east of it. The sandstone quarry to the east is 15 to 25 feet deep and covers about 2½ acres. The dolomite quarry has been excavated to about the same depth and covers about twice the area of the sand quarry. Numerous springs emerge near the bases of the quarries and are drained by ditches into water holes, which are emptied by 6-inch pumps. Between the two pits stands the sand mill, with its necessary trackage, while west of the dolomite quarry stands a mill for crushing that stone. Both quarries are operated on the same plan. The sandstone is a grayish to white, firm rock, in thin beds, having a total thickness of 15 to 25 feet. At the base of the sandstone lies a conglomerate of dolomite pebbles in a sandstone matrix, below which is a bed of hard, fine-grained, dove-colored dolomite with an uneven surface. At the top the sandstone has in places received a slight yellowish stain. Its grains are rather fine and under a field lens appear to be clear quartz, for the most part worn smooth. On the whole, the sand is a very light-colored, clean material. Compressed-air drills are used, and the sand is blasted and loaded into trams that are moved by gravity over tracks that converge at a turntable. The cars are drawn up an incline by cable into the mill, where they dump into a Blake crusher. When crushed the sand passes through three sets of rolls is washed twice by the "auger" method, is screened, dried by steam coils; screened again, and stored. From the stock house the sand is delivered through pipes into cars. This company owns and operates its railroad into Toledo. The output of sand aggregates 80 tons a week and it is shipped for glass making mainly to Ohio, Indiana, and Pennsylvania. An analysis of the sandstone is given on page 376,

The dolomite is not burned, nor sold as building stone, but is all crushed and used as fluxing material.

Holland.—Near Holland and Monclova, about 10 miles west of Toledo, interbedded sandstone and dolomite of the Monroe formation lie near the surface, as at Sylvania. About 2½ miles southwest of Holland are the quarries of the Ohio Stone, Cement, and Construction Company and of the Lake Shore and Michigan Southern Railway Company. Both quarries produce only crushed dolomite at present, although about fourteen years ago glass sand was obtained here, crushed, screened, cleaned by fan draft, and about 1,000 cars of it were shipped to the glass factory at Maumee. The

beds have a low dip to the west and in a generalized section are stratified as follows:

Generalized section near Holland, Ohio.

	Feet.
1. Glacial drift, clay, pebbles, and bowlders	0– 5
2. Dolomite, dense, fine-grained, in thin beds	10±
3. Sandstone, grayish-white, friable, of fine, rounded grains	15±
4. Dolomite, very hard, siliceous	2
5. Sandstone, similar to No. 3, bottom not visible, reported thickness	60

At the time of visit mills and quarries were closed for the winter and the old sandstone pit was filled with water. The sand appears to be of good grade, and as the quarries are connected with the Lake Shore and Michigan Southern main line by a well-constructed spur it is probable that the production of glass sand will at some time be resumed.

Toboso.—The E. H. Everett Company operates a large quarry one-half mile west of Toboso, a station on the Baltimore and Ohio Railroad, about 15 miles east of Newark. The quarry is in sandstone and conglomerate beds that outcrop in bluffs about 60 feet high on the right bank of Muskingum River. About 30 feet of sandstone are now worked after stripping the top 5 to 20 feet, which are of thin-bedded and shaly sandstone. The quarry can be worked probably to river level, about 15 feet lower, since the rock contains very little water to that depth. The fresh quarry face presents on the whole the appearance of a uniformly yellowish-brown sandstone. The rock is massive, cross-bedded, rather coarse-grained, and contains many layers of fine to coarse quartz pebbles. Some of these pebbles attain a diameter of three-fourths inch. A few streaks of white sandstone occur, composed of clear quartz and white, opaque quartz grains with a sprinkling of fine black specks, mainly of tourmaline and hornblende. Rarely there are seams, 2 to 4 inches thick, of siliceous iron ore and a few thin clay seams. The sand is drilled by steam, shot down, and loaded into skips, which travel on trucks to the middle of the quarry, where the skips are picked up by cable conveyer and carried to the mill. This cableway is about 900 feet long and well illustrates the efficiency of this method of handling sand. The sandstone is reduced first by a jaw crusher, next by a 16-hammer Williams mill, is next screened, and then ground in a wet grinder, or vat, in which two heavy iron rollers or "chasers" revolve at the ends of an axle. Washing is accomplished by two sets of "augers," each set consisting of two screws 10 feet in length, which carry the sand up inclined troughs against a flow of water. Water for washing is obtained from Muskingum River, which at times is very muddy, and it would seem preferable if clear water could be used. Possibly

this might be obtained from wells in the sandstone sunk below river level or to the first shale bed. When finished the sand is of a light brownish-yellow color, evidently containing a high percentage of ferric oxide as compared with most glass sands. The whole output, averaging 120 tons a day, is used by the American Bottle Company at Newark in the manufacture of green and amber bottles. The quartz pebbles, or gravel, separated in screening, constitute an important by-product of the sand and are sold for sand blasting.

Chalfants.—The Central Silica Company, with offices at Zanesville, operates quarries at Chalfants, Perry County, and at Rockbridge, Hocking County. The sandstone utilized at Chalfants lies high in the bluff, 125 feet above the Baltimore and Ohio Railroad track. The rock is a light grayish-yellow sandstone, massive at the base but becoming thin-bedded at the top, and about 35 feet thick. A few layers contain small, rounded quartz pebbles. The sandstone is underlain and overlain by clay, the upper clay, 3 to 10 feet thick, forming the surface of the hill. About 2 feet of sandstone is left at the base for a floor. The next 20 feet of beds are easily crushed and worked into glass sand, while the upper 10 to 12 feet, which is a very fine-grained material, indurated nearly to a quartzite, is crushed and mixed with the overlying clay to form ganister. The rock is lowered to a mill at the base of the hill by a cable incline, or tramway, crushed, screened, washed by "augers," and dried in a rotary drum. Of the finished product the glass sand goes to window and bottle plants in central Ohio, and the ganister and pebbles are mainly taken by steel mills in Detroit, Mich.

It is probable that a vast amount of good material is still available in the sandstone of Licking, Muskingum, and Perry counties.

Massillon.—The Everhard Company and the Sonnhalter Sand and Stone Company are deriving glass sand from the Massillon sandstone of the "Coal Measures." In the Everhard quarry about 40 feet of grayish and buff-colored sandstone are exposed. The rock of the lowest beds is coarse grained and at some places has been used for making grindstones. The middle beds are fine to medium grained, and the upper beds in places grade into shale. Shale underlies the sandstone and clay overlies it. The Everhard quarry is one of the oldest in the State, as it was opened nearly 70 years ago and at present the quarry face extends for more than one-fourth of a mile. The preparation of the sand is accomplished in a very compact and efficient mill. The process comprises crushing, rolling, screening, and drying. The drying is effected by two 16-foot double-draft rotaries, which burn natural gas. The sand is then elevated to cooling drums, where the fine dust is drawn out by fans. This method of removing the dust is supposed to obviate the necessity of washing the sand. The finished product is a light-yellow, fine

to medium-grained, partly angular sand. It is used mostly in Massillon by manufacturers of green and amber bottles. An analysis of the sand is given on page 376. The Everhard brick plant, consisting of a mill and 6 down-draft kilns has been built in the southern part of the quarry. Here fire clay mined $2\frac{1}{2}$ miles from the plant is utilized in the manufacture of a fine, mottled, fire-faced brick.

The Sonnhalter quarry, adjoining the one just described, produces glass sand and an even-grained, pink building stone. At this quarry the sand is washed and is dried in a Ruggles-Cole rotary dryer. An analysis of the Sonnhalter sand is given on page 376.

The quarries of the Massillon Sand and Stone Company and of the Wetter Steel Sand Company are also in the Massillon sandstone at a distance of one-half mile from the Sonnhalter quarry. These firms are now producing mill sands rather than glass sand, for which they have suitable material.

Small quantities of glass sand and larger quantities of sand for metallurgical purposes are produced at Barrs Mills, Dundee, and Strasburg, Tuscarawas County; Twinsburg, Summit County; Warwick, Wayne County; Killbuck, Holmes County, and Layland, Coshocton County, all in east-central Ohio.

Akron.—The quarry of the Akron White Sand Company is about 3 miles northwest of the center of Akron, on the line of the Northern Ohio Railway, on the brow of a scarp overlooking the valley of Cuyahoga River. At this place 12 to 20 feet of fine-grained, sharp, gray to buff sandstone above and 16 feet of pebbly conglomerate below are utilized.

The sand is crushed, rolled, screened, and dried, and is at present all sold for steel making, while the coarse pebbles from the conglomerate are used for concrete work.

Niles.—The National Sand and Stone Company operates a large quarry and mill about 4 miles south-southwest of Niles, near Austintown, on the Erie Railroad. Sandstone of Pennsylvanian age is quarried here from a large, open cut 25 feet deep. The face shows 8 feet of yellow to reddish sandstone at the top, with 15 feet of gray to white sandstone below. The beds have a slight dip to the north and are composed of a moderately coarse, subangular quartz sand, showing cross-bedding and containing in places near the base of the quarry some carbonaceous material in streaks and bands, one of which reaches 6 inches in thickness. The sand is sorted in the quarry and four grades are produced. The three best grades are sent to glass factories in Pennsylvania, principally for window glass, and the fourth-grade sand is sold for furnace and mill purposes. A symmetrically arranged mill completes the preparation of the sand, which passes in turn through a high-speed jaw crusher, a wet grinder, a reel screen, three sets of "auger" washers, further screens, and

then is pumped through a delivery pipe to various places in the large drain room. The floor of this room is constructed of coarsely crushed rock covered by mineral wool. The sand is dried in a stationary roaster, the essential parts of which are (1) an uncovered oblong, iron box, roughly estimated at 7 feet wide, 25 feet long, and 2 feet deep, fitted with a bottom of grate bars; (2) a fire box directly below the grate, but separated from it by a slanting sheet or plate of iron.

The sand is dropped from the belt into the open box, the capacity of which is about 25 tons. While drying it sifts slowly through the grate at the rate of 3 tons an hour, falls on the hot, inclined plate above the fire, and slides out onto a screw conveyer which operates in front of and at the base of the drier. After one more screening the sand is stored ready for shipment.

Glass sand is reported to be produced at Leavittsburg, Trumbull County, about 10 miles northwest of the Austintown quarries.

Undeveloped sand.—Sandstones as yet undeveloped, but known to be suitable for glass making and for other purposes for which a high-grade sand is in demand, occur in Holmes, Jackson, Knox, Licking, and Muskingum counties, mainly in the "Coal Measures" or Sharon conglomerate area of the State.

CHEMICAL ANALYSES.

The analyses here tabulated represent for the most part the best product from each locality. The only criticism that might be offered is that analyses are usually made from small selected samples and do not represent average carload lots. Samples taken from the cars invariably show slightly greater percentages of impurities.

Analyses of glass sands from Indiana, Kentucky, and Ohio.

Location.	Operator.	Sample.	Constituents.						Total.	Authority.
			Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Other items.		
INDIANA.										
Coxville	Acme Glass Sand Co., Terre Haute, Ind.		98.61	0.74	0.22	0.12	Tr.	Loss on ignition, 0.32.	100.01	W. A. Noyes, Rose Polytechnic Institute, Terre Haute, Ind.
Loogootee	Loogootee Glass Sand Co., Loogootee, Ind.	Selected	97.78	1.13	.10	.06			99.07	J. F. Elsom, New Albany, Ind.
Do	do	Crude	96.26	2.50	.92		0.16	Na_2O and K_2O, 0.13.	99.97	Operator: report of State Geologist.
KENTUCKY.										
Tip Top	Kentucky Silica Co., Louisville, Ky.	Selected, washed	99.14	.23	.02	.21	.08	CO_2+H_2O, 0.52	100.20	R. B. Hulme, Louisville, Ky.
	do	Selected	98.87	.21	.08	.24	.12	0.48	100.00	Operators of quarry.
	do	Crude	98.404	.751		.043	.372	H_2O, 0.271	99.841	Do.
OHIO.										
Sylvania	Toledo Stone and Glass Sand Co.		98.53	.18	.007	.67			99.387	Operators of quarry.
Chalfants	National Sand Co. (in 1902)		98.506	.69			.014	H_2O, 0.60	99.210	Professor Horton, Columbus, Ohio.
Massillon	Everhard Co., Massillon	Prepared for glass	97.50	1.50	.50		.50		100.00	Operators of quarry.
Do	Massillon Sand and Stone Co., Massillon.	do	98.611	.123	.033	.130	Tr.		98.897	Otto Wuth, Pittsburg, Pa.
Do	Sonnhalter Sand and Stone Co., Massillon.	do	99.60		.02	.23		Clay (?) 0.15	100.00	Jno. McNamee, Anderson, Ind.
Dundee	F. W. Meyers, Massillon, Ohio		98.45	.77	.14				99.36	F. A. Emmerton, Cleveland, Ohio.
Layland	Layland Stone and Sand Co. (in 1903).		98.78	.73	Tr.	.12	.04	Organic, 0.33	100.00	F. S. Schwab, Chicago, Ill.
Niles	National Sand and Stone Co.	First grade, washed	99.915	.062	.0019	.021	Tr.		99.9999	Otto Wuth, Pittsburg, Pa.
		First grade, not washed.	98.09	.75	.03	None.	.16	Loss on ignition, 0.33.	99.36	Pittsburg Testing Laboratory, Pittsburg, Pa.
		Second grade, not washed.	97.10	2.35	.14	.10	Tr.	H_2O, 0.31	100.00	Do.

NOTES ON VARIOUS GLASS SANDS, MAINLY UNDEVELOPED.

By Ernest F. Burchard.

Information relative to glass sands is occasionally obtained in connection with geological surveying, and some data thus procured are presented here to show the wide range in the geologic age and geographic distribution of suitable material.

Alabama.—Near Gate City, on the east side of Red Mountain, the formation heretofore mapped as the "Oxmoor" by the Alabama Geological Survey, composed of sandstone and beds of shale, has an outcrop width of 1,000 feet on both sides of Red Gap. The formation is nearly 200 feet thick and includes one sandstone bed about 75 feet thick. The beds dip southeastward at an angle of about 10°. The "Oxmoor" sandstone is of Mississippian age. It is composed of relatively pure quartz sand having very fine, subangular grains, which appear nearly white in mass. The rock is very soft, breaking down and crushing easily. Quarries which are worked intermittently for mill sand have been opened on both sides of Red Gap. About twenty years ago a small bottle plant operated at Gate City demonstrated that this sand was suitable at least for common bottles and fruit jars. It has been used also by the Dixie Glass Works at Tallapoosa, Ga.

Gate City, just on the outskirts of Birmingham, is on the line of five railroads which enter Birmingham by way of Red Gap, and is therefore favorably situated with regard to material, fuel, transportation, and market. No glass factory can be operated as many months of the year at this latitude as can those in the North, but if window glass could be made from this sand there is little doubt that it would find a ready market.

About seven-eighths mile northeast of Trussville, a station on the Alabama Great Southern Railroad, 15 miles northeast of Birmingham, sand quarries utilize the "Oxmoor" sandstone, as well as a reddish loam that overlies it. This loam may be of Tertiary (Lafayette) age. The characteristics of the "Oxmoor" sandstone here are similar to those of the beds at Gate City. Analyses of samples of this sandstone taken at both localities are given on page 382. At present the silica

sand, with an admixture of the red loam, is shipped in large quantities to mills at Birmingham, Bessemer, Ensley, and New Decatur, Ala., where it is used for molding purposes.

At North Birmingham the Lookout sandstone, of early Pennsylvanian age, is quarried for sand-lime brick making. Certain beds of this sandstone might prove pure enough for glass. The rock is of coarser grain than the "Oxmoor," but is very firmly cemented and is consequently harder to crush. Its chemical composition is shown on page 382.

Arkansas.—Attention was called in an earlier paper [a] to deposits of glass sand of excellent grade on White River, in northern Arkansas. These are practically inexhaustible and of the same age (Ordovician, St. Peter formation) as the great Pacific, Missouri, and Fox River, Illinois, deposits. It is of interest to note that near Guyon, on the White River branch of the Missouri Pacific Railroad the exploitation of these deposits has recently been undertaken, and it is reported that the glass sand is to be used for flint, window, and bottle glass at Coffeyville, Kans. (See p. 382 for analyses.)

Georgia.—The rare use of a river sand for glass making is reported from Augusta, Ga. Sand obtained along Savannah River is shipped to Chattanooga, Tenn., where bottles are successfully made from it. The sand is composed of fine to coarse angular grains of quartz, both clear and milky varieties being present. In mass it has a light gray or dingy white color.

Florida.—The unusual cleanness and even grain of the Gulf beach sand at Pensacola, Fla., suggested to the writer its suitability for glass making, and analysis of this sand (see p. 382) shows that it possesses the requisite purity. The sand is slightly coarse, the greater part of it passing a 20-mesh sieve, but not 40-mesh. Although at present remote from any glass-making centers, the deposit is not far from lines of rail and water transportation.

Iowa.—The Potsdam sandstone (Cambrian) and the St. Peter sandstone (Ordovician) occurring along Mississippi River in northeastern Iowa have already been mentioned as available glass-making materials.[b] In addition, it is now possible to give certain information concerning the Dakota sandstone (Cretaceous) in the northwestern part of the State. This rock has been found in quantity and purity sufficient to make it a possible source of sand for making bottle glass. It outcrops in bluffs along Floyd River valley northeast of Sioux City and has been quarried for building and molding sand near the

[a] Burchard, E. F., Glass sands of the middle Mississippi basin: Bull. U. S. Geol. Survey No. 285, 1906, p. 470.

[b] Burchard, E. F., ibid., p. 471.

Springdale station of the Sioux City-Leeds trolley line. Between 35 and 40 feet of massive, cross-bedded, soft sandstone with thin clay partings are exposed. The top is overlain by 10 to 80 feet of loess. The sand is a fine to medium grained quartz, rather angular, and carries a small proportion of mica flakes. Its color ranges from pure white through gray to yellow and dark brown. The average is light yellow. Where iron stained the objectionable material is usually hard enough to be thrown out in blocks. Generally the rock is so friable that it could conveniently be worked by hydraulic methods. This sandstone is well situated for quarrying and transportation, as it is close to the tracks used jointly by the Chicago, St. Paul, Minneapolis and Omaha and the Illinois Central railroads. The Dakota sandstone is exposed also at the base of Prospect Hill in the Missouri River bluffs, and the top of the formation is low in the bluffs of Big Sioux River, opposite Riverside Park. Fuller descriptions of the Cretaceous sands, clays, and limestones of this region and a map of their distribution is given in a local publication.[a]

Kansas.—Probably nowhere in the United States is there at present a greater need for a local supply of glass sand than in southeastern Kansas. In the gas belt there are 10 window-glass factories and 8 flint or bottle and jar factories in Kansas and 1 factory across the line in Indian Territory. All these are obtaining sand from eastern Missouri, and in addition to the selling price of the sand the consumers are paying three to three and one-half times that amount in freight charges. Besides the disadvantage of the high cost of sand these plants are at times subjected to a sand famine, due to the inability of remote producers to fill their orders promptly and to the inability of railroads to move the material when it is needed. The sandstone in the Buxton formation has been thoroughly prospected with a core drill at several localities near Fredonia. A typical section revealed by this drill is as follows:

Section of drill hole in Buxton formation near Fredonia, Kans.

	Ft.	in.
Light-brown, slightly coarse-grained sandstone	3	1
Light yellowish-gray, medium-grained sandstone, with a few iron-oxide specks near top and bottom of bed	4	10
Brownish, medium-grained, speckled sandstone, considerably stained by iron oxide	7	2
Gray calcareous sandstone	0	6
Total	15	7

[a] Burchard, E. F., Geology of Dakota County Nebraska: Proc. Sioux City Acad. Sci. and Letters, vol. 1, 1904, pp. 135–184.

In January, 1907, a trial of this sand was begun at the works of the Fredonia Window Glass Company. The sand was hauled by wagon to the works and was found to make glass of excellent quality.

Near the town of Fall River the Buxton sandstone is exposed at several places by the drainage system of Fall River. The sandstone here is about 20 feet thick and is parted near the middle by a thin clay seam. The upper bed of sandstone is generally iron stained, especially at the top and immediately above the clay seam. Below the clay seam is 4 to 5 feet of very clean, grayish-white, angular sandstone, rather friable. This deposit is close to the Frisco Railroad tracks. West of the town it would have to be quarried from a pit, but east of the town it rises in a bluff that stands about 30 feet above railroad level. Associated with the sandstone, but somewhat above the beds just described, is a limestone, probably the Painterhood,[a] which might be quarried at the same time and used for glass making. Analysis of a small sample of this rock by George Steiger, of the United States Geological Survey, is as follows:

Analysis of limestone from Fall River, Kans.

Silica (SiO_2)	2.56
Alumina (Al_2O_3)	1.55
Ferric oxide (Fe_2O_3)	.50
Ferrous oxide (FeO)	.47
Magnesia (MgO)	.06
Lime (CaO)	51.98
Water (H_2O)	1.36
Carbon dioxide (CO_2)	41.13

Missouri.—Just south and east of the town of Versailles, Mo., lies a belt of saccharoidal sandstone, which is exposed at the top of the escarpment overlooking the ravines at the headwaters of Little Gravois Creek. This sandstone is almost everywhere capped by iron-stained quartzite, in some places cherty. The rock strikes northeast-southwest and has a low dip to the southeast. It is overlain in places by cherty beds and a very fine-grained sandstone or "cotton rock." The sandstone is regarded as the equivalent of the Roubidoux sandstone, of the Ordovician system, although some of the beds may be sandstone of Carboniferous age that has been deposited in connection with the thick masses of cannel coal that are found here in pockets or sink holes. The apparent thickness of the sandstone reaches 25 feet in places, although the actual thickness may be less than this, since the exposures are principally on hillsides that slope in the direction of the dip. Below the cap of quartzite the sand is white and friable,

[a] Schrader, F. C., and Haworth, Erasmus, Economic geology of the Independence quadrangle, Kansas: Bull. U. S. Geol. Survey No. 296, 1907.

except near joint planes, where it is somewhat iron stained and harder. The sand is white to yellowish, water-worn, and partly subangular; 100 per cent of the grains pass a 20-mesh sieve, 23 per cent pass a 40-mesh, 23 per cent pass 60-mesh, and 11 per cent pass 80-mesh. Therefore the sand, although uneven, is mostly of medium grain. The beds most suitably located for working are in the south half of sec. 32, T. 43 N., R. 17 W., where the rock outcrops within one-fourth mile of the Chicago, Rock Island and Pacific Railway.

Nebraska.[a]—The most accessible and prominent exposures of Dakota sandstone in this State are near Ponca, Jackson, Homer, Tekamah, Ashland (at mouth of Salt Creek), Lincoln, and Beatrice, and in the southern part of Jefferson County. The sand is variably indurated. At places it contains siliceous cement and is a quartzite. There is much less calcium carbonate in the stone than is usually supposed. It may be said that ferric oxide is the prevailing matrix. Generally the sandstone is friable and easily crushed. It is thin bedded where interstratified with shales or clay and mostly massive in the upper and lower parts of the formation. At some places massive ledges grade laterally into arenaceous clays within a short distance. The color ranges from gray to the yellows and browns, varying with the amount of iron stain present. The iron oxide covers or coats the grains, but rarely occurs as an impurity in the quartz. The sands may be freed of iron by washing. The chemical analysis of a badly stained sample taken at Robbers' Cave, near Lincoln (see p. 382), shows that the sand, if washed, might be used for green or dark glass.

When sieved, most of this sand was caught on meshes 30, 40, and 50, so that it is of remarkably even grain. It is composed largely of quartz, except when clay and mica are found. These are present where the sand rock grades horizontally into clay. In general the friable sand rock is clean, except for the iron.

[a] Communicated by Dr. Geo. E. Condra, Dept. of Geol., Univ. of Nebraska, Lincoln, Nebr.

Analyses of undeveloped glass sand from various localities.

Location.	Sample.	Constituent. Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Other items.	Total.	Authority.
ALABAMA.									
Gate City	Sand	99.80	0.75	0.31	0.05	0.10	[a]0.16	100.11	R. S. Hodges, University, Ala.
Do	Sandstone	97.22	1.88	.24	.06	.09	.21	99.70	Do.
Irondale	do	97.93	1.05	.19	.06	.33	.12	99.68	Do.
Trussville	Sand	98.05	.22	.20	Tr.	.78	...	99.25	E. S. Campbell, Trussville, Ala.
Do	do	98.30	.08	.19	.09	.02	.09	99.67	R. S. Hodges, University, Ala.
North Birmingham	Sandstone	97.30	1.39	.33	.07	.18	.16	99.43	Do.
ARKANSAS.									
Guyon	Sandstone	99.52	Tr.	.054	Tr.	Tr.	[b].016	99.59	R. V. Pepperberg, University of Nebraska, Lincoln, Nebr.
FLORIDA.									
Beach sand, Gulf of Mexico at Pensacola.	Crude	99.65			(c)			99.65	George Steiger, United States Geological Survey.
IOWA.									
Sioux City, Springdale station.	Averaged	96.90	1.22	.28	.14	.05	[a]1.07	99.66	George Steiger, United States Geological Survey.
KANSAS.									
Greenwood County, SE. ¼ sec. 13, T. 28 S., R. 12 E.	Selected from different beds same vertical section.	98.24	.57	.35	.06	.04	.72	99.98	George Steiger, United States Geological Survey.
Do		97.81	.73	.35	.18	.05	.80	99.92	Do.
Do		98.02	.81	.26	.08	.06	.81	100.04	Do.
Fall River, ½ mile east of Frisco railroad station.		97.28	.96	.80	.13	.04	.73	99.94	Do.
MISSOURI.									
Versailles	Averaged	99.03	.40	.13	.29	.11	.44	100.40	George Steiger, United States Geological Survey.
NEBRASKA.									
Robbers' Cave, near Lincoln.	Crude	95.76	.48	1.81	.24	.16	[d]1.55	100.00	George Borrowman, University of Nebraska, Lincoln, Nebr.

[a] TiO_2. [b] Loss on ignition. [c] None. [d] Undetermined.

QUARTZ AND FELDSPAR.

FELDSPAR AND QUARTZ DEPOSITS OF MAINE.

By Edson S. Bastin.

INTRODUCTION.

The commercially important feldspar and quartz deposits of Maine all belong to a single type of rocks known to the geologist as pegmatites. These rocks may be defined as coarse-grained crystal aggregates which as a rule have the composition of granite, their principal constituents being feldspar, quartz, and mica, usually with subordinate amounts of other minerals. The pegmatites of Maine were studied by the writer during part of the summer of 1906, the work being done in cooperation between the State Survey Commission and the United States Geological Survey.

GEOGRAPHIC DISTRIBUTION.

These deposits are confined largely to Sagadahoc, Cumberland, Androscoggin, and Oxford counties, in southwestern Maine, though occurring to some extent in association with all the large granite masses in other parts of the State. Excellent exposures occur in many open pits, from which feldspar, quartz, mica, or gem minerals have been mined, and in the cliffs along the seacoast, especially in the Boothbay Harbor region.

GEOLOGIC OCCURRENCE.

The pegmatites form masses that are plainly intrusive in the surrounding rocks. The latter are for the most part shaly sediments, probably of early Paleozoic age, which have been closely folded and altered to slates and schists. This alteration took place at the close of Ordovician time, during a period of dynamic or regional metamorphism which affected most of New England. In many of the more argillaceous layers the regional metamorphism has developed a fissility which is in some places highly inclined to the bedding planes and in others nearly parallel to them, depending on the character of

the folding. In the more quartzose layers, however, secondary fissility has been developed but weakly if at all, and such layers are in general numerous enough to define the trend of the original bedding and to render this the direction of easiest parting so far as the intrusion of considerable masses of igneous rock is concerned. Over large areas the rocks have been thrown into a series of closely compressed (isoclinal) folds standing in highly inclined positions, and in such areas the secondary fissility is as a rule nearly parallel to the bedding planes. The form of the pegmatite bodies, which in their intrusion followed in general the direction of least resistance, is therefore dependent largely on the position of the bedding planes in the surrounding sedimentary strata. Their form in regions of highly inclined strata is well shown along the shore near Boothbay Harbor, where most of the pegmatite masses are highly inclined and dikelike in form, though differing from the many dikes of diabase and of normal granite of the same region in not showing parallel walls, the typical form being a succession of lenticular masses produced by repeated pinchings and swellings of the dike. In regions where the sedimentary strata are but slightly inclined the pegmatite masses are flat-lying and sill-like rather than dikelike in form, though showing the same tendency toward lenticular form or toward repeated pinchings and swellings along the length of the sill. On account of their flat-lying character many pegmatite bodies of the latter type cover considerable areas and show a rather irregular surface outcrop. Other bodies are exposed only in cross section in a quarry cut or along the side of a valley. One of the best examples of the flat-lying pegmatite masses is exposed in the bed of Androscoggin River just above the road bridge between Lewiston and Auburn. The inclosing rocks here are gray to purplish slates that show distinct bedding and dip to the northeast at angles of about 30°, and several sill-like masses of pegmatite are intruded parallel to their bedding planes. The largest mass is lens-shaped, with a maximum thickness of 15 feet, and is exposed laterally for 300 feet, though probably extending much farther. The position of the falls here is undoubtedly dependent on the fact that this sill and the injected sediments adjacent to it offer more resistance to erosion than most of the schists. The pegmatite body that is worked for its gem minerals at Mount Mica, in Paris, Oxford County, is another example of the flat-lying, sill-like type. The sedimentary schists here dip 20° to 30° SW. and the pegmatite mass, apparently 20 feet or so in thickness, has a similar dip. Other pegmatite masses are unlike either of the types just described, but seem to be large, somewhat irregular stocks of uniform character throughout. One of the best examples of this type is Streaked Mountain, in the northwest corner of the town of Hebron, Oxford County, which is almost wholly pegmatite and seems to be a great dome of this rock.

ORIGIN AND AGE.

It is not possible here to enter into a detailed discussion of the origin of these pegmatites. There can be no doubt, however, that they represent simply one phase of the granitic intrusions so abundant in the southern and southeastern parts of the State. The evidence of this is found in their distribution with respect to the areas of true granite, in the presence of dikes and irregular intrusions of true granite in all the regions where pegmatite occurs, and in an actual gradation from pegmatite into fine-grained granite observed at many localities. The granites of the eastern part of Maine are known to be late Silurian or Devonian in age, and there is every reason to believe that the granites of southern Maine, with their associated pegmatites, are of similar age. They are certainly later than the period of dynamic metamorphism at the close of the Ordovician.

GENERAL CHARACTERS.

COMPOSITION.

The pegmatites in all parts of the State show great similarity in the principal minerals developed, although they exhibit notable differences in the minor constituents. In mineral composition they are essentially coarse granites, the principal light-colored constituents being potash feldspar, quartz, and muscovite, and the principal dark-colored constituents black mica (biotite) and black tourmaline. In pegmatites where black mica is abundant, black tourmaline is, as a rule, rare or absent, and vice versa. Accessory constituents that are almost invariably present are garnet, magnetite, and opaque green beryl. Accessory minerals that are present only in certain pegmatites number over 50 species; but perhaps the most important are lepidolite or lithium mica; blue, green, and pink tourmaline; transparent green or golden beryl, topaz, and amethystine quartz. In some places, as at Mount Mica, in Paris, Oxford County, certain of the gem minerals are present in considerable quantity and are of the finest quality, so that the pegmatite can be profitably exploited as a gem deposit.

COARSENESS AND TEXTURE.

The pegmatites show remarkable variation in coarseness, some, especially the narrower dikes and sills, being little coarser than coarse-grained granites, though differing from the latter in texture. In others single crystals of nearly pure feldspar may be 20 feet across, and single beryl crystals may reach the diameter of a hogshead. The major part of the pegmatites are nearer the lower limit of coarseness than the higher. Only the coarser bodies are commercially valuable for their feldspar, quartz, mica, or gem minerals, and these constitute

a relatively small percentage of the total mass of pegmatite material. In most of the pegmatites worked commercially the feldspar and quartz crystals do not average more than 4 or 5 feet in diameter.

The most striking characteristic of the texture of the pegmatites is its extreme irregularity. In a mass of typical granite there is considerable uniformity in size among grains of the same mineral species, but in the pegmatites there is no such regularity. A feldspar crystal, for example, is as likely to be two or three or even ten times as large as an adjacent crystal as to be of similar size. In most of the pegmatites there is also much graphic granite, consisting of an intimate intergrowth or interpenetration of single crystals of quartz and feldspar, the quartz forming, on certain faces of the feldspar crystals, a peculiar angular pattern somewhat resembling the cuneiform inscriptions of the ancients. Fine-grained phases pass into coarser graphic granite and this by decrease in quartz may pass into masses of pure feldspar, or by decrease in feldspar into masses of pure quartz. Much of the material mined as "spar" is coarse-grained graphic granite containing from 10 to 20 per cent of free quartz.

In the great majority of pegmatite bodies there is no regularity whatsoever in the distribution of the different minerals. The mica plates show, in many places, a tendency to group themselves along certain planes, but these seem to have no definite orientation with respect to the general outline of the mass, and this arrangement is by no means universal. A pegmatite which is of excellent commercial quality as regards its feldspar content may grade within a short distance and in a wholly irregular manner into rock which is worthless because of its large percentage of quartz or the abundance of biotite, black tourmaline, or garnet.

USES.

FELDSPAR.

Practically all of the feldspar mined in Maine is used in pottery manufacture, its main application being as a constituent of both body and glaze in true porcelain, white ware, and vitrified sanitary ware and of the "slip" (underglaze) and glaze in so-called "porcelain" sanitary ware and enameled brick. The amount of feldspar in the body of these wares generally falls between 15 and 35 per cent, though in some it is less and in some more. In glazes the percentage of feldspar is as a rule between 30 and 50. Small amounts of very pure spar, carefully hand picked, are occasionally shipped for use in the manufacture of artificial teeth. Feldspar mined in other Eastern States is also used principally for pottery purposes, though finding some application in glass making, in dentistry, and in the manufacture of certain polishes and scouring soaps that are less abrasive than those in which ground quartz is used. Much interest

has recently been aroused in the use of potash feldspar for fertilizing purposes. Potash is an important plant food which in fertilizers has usually been applied in the form of easily soluble potash salts imported from Germany. Recent experiments conducted by the Department of Agriculture have shown that certain plants are capable of readily decomposing feldspar that has been ground to the fineness usually demanded in the pottery industry (200 mesh and finer). The Department of Agriculture is now carrying on an exhaustive series of experiments to determine what plants are benefited by the use of feldspar and the exact character of the materials needed, and to avoid failures due to the misuse of these materials it is safer for fertilizer manufacturers and others to await the published report on these tests.

QUARTZ.

At present (1906) there is no market for the quartz mined in Maine, even when produced as an accessory in feldspar mining. At some of the mines it is thrown on the waste heaps; at others it is collected in piles in the hope of a future market. It formerly found a somewhat unsteady market for pottery and sandpaper purposes. The low value of the crude material, about $2 per ton at the mines, makes it impossible for Maine quartz to compete with quartz from Connecticut, New York, Pennsylvania, and Maryland quarries, which are nearer to the markets.

METHODS OF MANUFACTURE.

Feldspar is ground at two mills in Maine—one at Cathance station, near Brunswick, operated by the Trenton Flint and Spar Company, of Trenton, N. J.; the other at Littlefield station, near Auburn, operated by the Maine Feldspar Company. The method of grinding is similar at both of these mills and is the same as that generally used by feldspar and quartz grinders elsewhere in the United States. The lump material as it comes from the quarries is first crushed in a chaser mill, of which each factory usually has several. This consists of two burrstone wheels about 3 to 5 feet in diameter and 1 to 1½ feet thick attached to each other like the wheels of a wagon by a horizontal axle. This axle is attached at its center to a rotating vertical shaft which causes the wheels to travel over a burrstone bed, the feldspar being crushed between the two burrstone surfaces. The material as it comes from this mill is screened, the tailings being returned to the chaser mills for recrushing and the fines going to ball mills for their final grinding. The ball mills consist of steel cylinders revolving on a horizontal axis. They are usually lined either with wooden blocks or blocks made of highly siliceous brick and are charged with pebbles of Norway or French flint 2 to 3 inches in

diameter. A single load of feldspar is usually ground for four to six hours in these mills and in that time is reduced to a fineness of at least 200 mesh. The material is then ready for shipment either in bulk or in bags.

Quartz used for pottery purposes is ground in the same manner as feldspar, but none is now being produced in Maine.

COMMERCIAL AVAILABILITY OF DEPOSITS.

The answer to the question whether it will pay to work a given feldspar or quartz deposit is dependent on a number of different factors. Considered as a whole, the Maine deposits have the disadvantage, as compared with those of Connecticut, New York, Pennsylvania, and Maryland, of being far from the markets, a feature which renders the mining of quartz wholly unprofitable. The bulk of the material mined in Maine under the commercial name of "spar" is not pure feldspar, but an association of feldspar and free quartz, usually intergrown in the form of a coarse graphic granite. In the past a number of the quarries have produced much larger amounts of feldspar free from quartz than can now be mined. The requirements of the potter's trade demand that in general the percentage of free quartz associated with the feldspar in the ground product shall not exceed 15 or 20 per cent, and certain potters demand a spar which is nearly pure, containing probably less than 5 per cent of free quartz. In order to be profitably worked, in most feldspar mines in Maine, between one-fourth and one-half of the total material quarried must carry under 15 to 20 per cent of free quartz.

A factor of the utmost importance is the amount and distribution of the iron-bearing minerals—black mica, garnet, and black tourmaline. For pottery manufacture the spar must be practically free from these minerals, which if present in the ground spar produce brown discolorations in white ware on burning. To be workable commercially, these minerals must be so rare or so segregated in certain portions of the deposit that they can be separated from the feldspar without much more hand sorting and cobbling than is necessary anyway in the separation of the highly feldspathic material from that which is highly quartzose. A number of coarse-grained masses of pegmatite with feldspar of excellent quality are rendered worthless for pottery uses by the abundance of one or more of these iron-bearing minerals. The presence here and there of minute flakes of white mica (muscovite) can hardly be avoided even in the highest grades of commercial feldspar, and chemically this mineral is not injurious. It is, however, exceedingly difficult to pulverize the flakelike flexible plates of mica to a fineness equal to that attained by the feldspar, and it is therefore necessary in mining to separate the muscovite carefully from the spar.

Under present conditions in Maine it is usually essential to commercial success that the feldspar deposits be located not farther than 2 or at most 3 miles from the railroad, so that the cost of haulage from the mines to the cars will not exceed 75 cents or $1 per ton, the average price for most of the crude spar in Maine being about $3 f. o. b. at the mines. The feldspar mills are situated on the railroads as close as possible to the mines. Nearly all the ground and crude spar is shipped to Trenton, N. J., and East Liverpool, Ohio, where many of the largest potteries of the country are located. The average price of the ground spar f. o. b. mills is about $9 per short ton.

METHODS OF MINING.

The feldspar and quartz of Maine are all mined from open pits. Unlike the deposits of Maryland and southern Pennsylvania, there is little or no associated kaolin formed by the decomposition of the feldspar. This is due to the fact that the Pennsylvania-Maryland region is unglaciated, whereas in Maine the ice planed off nearly all the products of rock decay. It is necessary, therefore, to sink drill holes and blast out most of the material with powder or dynamite. It is then broken up with sledges to lumps under 6 or 8 inches in size, and at the same time the quartzose and iron-bearing portions are sorted from the feldspar. The rock is hauled by teams to the mills.

DESCRIPTION OF PRINCIPAL LOCALITIES.

GEORGETOWN, SAGADAHOC COUNTY.

The Georgetown quarry is about 1½ miles northeast of Bay Point Landing, near the mouth of Kennebec River, and is readily reached by team from Five Islands, 4½ miles to the northeast, on Penobscot River. It is operated by the Golding Sons' Company, of Trenton, N. J. The spar is hauled about one-fourth of a mile by teams, then loaded onto scows and carried up Kennebec River 10 miles to Bath, where it is loaded onto cars for shipment to Trenton, N. J., and East Liverpool, Ohio. In the past some shipments have been made by sea. The quarry covers an area of about 3 acres and at its south end has a maximum depth of approximately 50 feet, though most of the quarry is much shallower.* The pegmatite is inclosed by metamorphic sedimentary schists trending somewhat east of north. These are highly inclined and are somewhat injected by granitic materials, so that locally they become gneisses. The pegmatite mass is plainly intrusive in these shists, and its greatest length is parallel to their trend; it thus forms in reality a short dike. The present quarry openings cover almost the whole area of outcrop of this mass, and future work must consist largely in deepening the present pit. There seems every reason to expect that the rock will continue of good quality and of about

the same dimensions to a considerable depth. A number of other dikes of pegmatite of similar size and shape occur in this vicinity and some of them have been worked to a slight extent. None of these, so far as seen, showed any large amount of feldspar of the grade required for pottery purposes.

The rock now quarried is mainly a coarse graphic intergrowth of feldspar and quartz, and it is estimated that about 50 per cent of the total material excavated is of commercial grade. The quarry has been worked intermittently for over thirty years, and in the past has produced larger amounts of perfectly pure spar than at present. It is said that a single blast would sometimes loosen 100 tons of almost pure feldspar. Black mica is almost wholly absent. Black tourmaline is somewhat abundant, but is so aggregated in certain parts of the deposit that it can be easily separated in mining. Some deep flesh-colored garnet is also present. Muscovite (white mica) is only locally abundant. The feldspar is cream colored and is largely of the potash variety, as shown by the following analysis made by the Pittsburg testing laboratory:

Analysis of feldspar from Georgetown, Me.

SiO_2	65.23
Al_2O_3	20.09
Fe_2O_3	.71
K_2O	11.60
Na_2O	2.00
Loss on ignition	.36
	99.99

TOPSHAM, SAGADAHOC COUNTY.

Two quarries in Topsham are operated by the Trenton Flint and Spar Company, of Trenton, N. J. The larger quarry is about $1\frac{3}{4}$ miles northwest of Cathance station and the smaller about half a mile southwest of the larger. The spar is hauled by teams from these mines to the mill, which is located on Cathance River near Cathance station. During wet seasons the water power of the river is utilized, but the mill is also equipped with steam. The grinding machinery consists of three chasers and four ball mills, each capable of grinding a ton of spar in four to five hours. The capacity of the mill is about 16 tons a day. The quarry, which is the largest one in Maine, covers an area of several acres and is about 50 feet in maximum depth. In its southern portion the rock is very similar to that at the Georgetown quarry, being largely a graphic intergrowth of feldspar and quartz in greatly varying proportions. At the north end of the quarry the pegmatite is much coarser and graphic texture is practically absent. At one place a continuous bed of white quartz 10 feet high and 50 feet long is exposed, and adjacent to it is a mass of pure feldspar 15 feet across. The principal iron-bearing mineral at

his quarry is black mica (biotite) in lath-shaped crystals up to 3 or 4 eet in length. Most of it can be separated readily from the feldspar. Garnets are not abundant. Muscovite or white mica is uniformly of the A variety and nowhere of commercial grade. It is concentrated principally along certain planes and is not difficult to separate rom the highly feldspathic rock. The surrounding rocks at this quarry are metamorphic schists, probably of sedimentary origin, which dip at steep angles and strike slightly east of north. Next to he pegmatite mass they have been much injected and also show igns of softening. The form and extent of the pegmatite body can not be accurately determined because of a scarcity of outcrops.

The smaller quarry one-half mile southwest of the large one was pened in 1906 and covers only about an acre, with an average depth f about 10 feet. In general the materials are similar to those of the arge quarry. Some masses of pure feldspar are 10 feet across. Outcrops are very few in the immediate vicinity of this quarry and he form of the pegmatite body can not be determined. In both of hese quarries the feldspar is mainly cream colored and of the potash varieties microcline and orthoclase. Crystals of white feldspar showng twinning striations on certain of their faces are albite, a soda eldspar, but they are not abundant.

Another quarry within a few rods of the small quarry just described s worked by the Maine Feldspar Company, of Auburn, Me. The output is very small and the character of the rock is entirely similar o that at the adjacent quarries. Feldspar has been quarried in the past at several other points in this vicinity, notably at Mount Ararat, near Topsham village.

AUBURN AND POLAND, ANDROSCOGGIN COUNTY.

The third important feldspar locality is Mount Apatite, in the town of Auburn, about 6 miles west of the city of Auburn. The quarry here is worked by the Maine Feldspar Company, the crude spar being hauled by team about 2 miles to the mill at Littlefield station, on the Grand Trunk Railway. This mill is equipped with one chaser larger than that used in most spar mills, each burrstone weighing 3½ tons. The ball mill also is longer than those commonly used and grinds 3 tons every four and one-half hours, the capacity of the mill being about 15 tons in twenty-four hours.

The rock mined at Mount Apatite is taken from a number of pits 75 to 150 feet long, about 50 feet wide, and 10 to 20 feet deep. These form part of a single mass of pegmatite covering most of the summit of the hill and intrusive into schists of probable sedimentary origin. Exposures are not continuous enough to trace the exact outlines of the mass, but its greatest extension seems to be in a north-northeast and south-southwest direction, parallel to the trend of the surrounding

schists. As at the other feldspar localities much of the commercial material quarried is a coarse graphic intergrowth of quartz and feldspar, though there are also very considerable amounts of pure feldspar. The latter is mostly cream colored, with here and there bluish-gray streaks and blotches. It is a potash feldspar, though small amounts of soda and lime-soda feldspar are associated with it. Both black mica and black tourmaline are present, but they are abundant only in places and are readily separable from the commercial spar. A considerable amount of quartz, white to dark gray in color, occurs and is saved, though at present finding no market. At the time of the writer's visit (August, 1906) about 300 tons of quartz were piled up at the quarries. There seem to be large amounts of excellent spar available at Mount Apatite for some time to come.

A smaller quarry, operated by A. R. Berry, is situated in the town of Poland, about 1 mile south of Mount Apatite. Irregular excavations here cover an area of about 2 acres and have a maximum depth of 18 to 20 feet. The spar is all sold to the Maine Feldspar Company and hauled about 3 miles to their mill at Littlefield. The character and mode of occurrence of the feldspar and quartz are similar to those at Mount Apatite. At both these localities lithium mica is occasionally found and tourmalines and beryls of fine gem quality also occur. They are not abundant enough, however, to pay for working these deposits for gems alone.

HEBRON, OXFORD COUNTY.

A small feldspar and mica mine has been opened during the last year (1906) about 1½ miles north of Hebron village, near the Buckfield road. This mine is located on the farm of Alton Hibbs and is being operated by J. A. Gerry, of Mechanic Falls, Me. The pegmatite is exposed for a distance of 300 to 350 feet along the southwest side of a small creek valley, the average width of outcrop being about 30 feet. Schists bound the pegmatite mass on its southwest side, their trend varying from N. 30° W. to N. 50° W. and averaging about N. 45° W. Their average dip is 45° NE. The northeast border of the mass is wholly obscured by glacial drift, which fills the bottom of the valley. The strippings and small excavations already made show numerous bodies of pure feldspar 2 to 3 feet across and much graphic granite containing only a small percentage of quartz. It is estimated that 60 per cent of the material mined is of commercial grade. No predictions can be made as to the continuance of this rock beyond the limited area of present exposure or in depth. It is probable, however, that its greatest extent is in a northwest-southeast direction, parallel to the trend of the neighboring schists. The feldspar is of the potash variety and is cream-gray to blue-gray in color. Black mica is scanty

in amount, but black tourmaline is moderately abundant. Its separation, however, does not entail great labor. Muscovite (white mica) is very abundant and of commercial quality in a zone about 4 feet wide next to the southwest wall of the pegmatite mass, but in the remainder of the rock it occurs only in scattered plates, mostly not more than 2 to 3 inches across. At the time of the writer's visit (September, 1906) no spar had been marketed. The material must be hauled about 3 miles to Hebron station, on the Portland and Rumford Falls Railway.

OTHER QUARRIES.

Numerous other quarries in Maine which have in the past produced feldspar and quartz were visited by the writer and will be described in the final report.

PRODUCTION.

The total production of crude feldspar in Maine for 1905 was 2,312 long tons, valued at $6,405. The production of ground spar was 9,317 short tons, valued at $83,850.

FELDSPAR AND QUARTZ DEPOSITS OF SOUTH-EASTERN NEW YORK

By Edson S. Bastin.

INTRODUCTION.

The feldspar and quartz deposits near Bedford village, in Westchester County, N. Y., were visited by the writer in January, 1907. These deposits have been described briefly in the reports of the New York State Museum[a] and from that description a part of the material for this report has been obtained.

The quarries here described are located near Bedford village and 2 miles to the south in the town of North Castle. They can be reached by a 6 to 8 mile drive from Mount Kisco, a station on the Harlem division of the New York Central Railroad, 38 miles north of New York City.

GEOLOGIC RELATIONS.

The feldspar and quartz of these quarries occur as constituents of a class of rocks known to the geologist as pegmatites. In their mineral composition these rocks are closely allied to granites, the principal constituents in both being feldspar, quartz, and mica. The grain of the pegmatites, however, is as a rule exceedingly coarse and the texture very irregular, as brought out in another part of this bulletin (pp. 385–386) in the description of the pegmatites of Maine.

The rocks of the region are a mica schist (the Hudson schist) and scattered masses of crystalline limestone (the Stockbridge dolomite). Both of these rocks have been shown to be of sedimentary origin, though extensively altered by metamorphic action. They now lie in a series of closely compressed folds, whose general trend in the region here described is northeast and southwest. The Hudson schist has been shown to be of Ordovician age; the Stockbridge dolomite is in part Ordovician and in part Cambrian.

In the vicinity of the feldspar and quartz quarries and along much of the road between Bedford village and Mount Kisco the Hudson

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[a] Bull. N. Y. State Museum No. 102, 1905, p. 69.

schist has been injected by granite, pegmatite, and basic igneous rocks, so as to show locally a gneissic texture. Here and there, as along the road from Bedford village to the Hobby quarry, in North Castle, small masses of normal granite occur. There can be little doubt that the pegmatites, which are of commercial importance in this region, are simply one phase of the granitic intrusion and injection of the Hudson schist, and that, like the granites, they are Silurian or later in age.

KINKLE QUARRY.

This quarry is situated on the east and northeast slopes of a small hill about three-fourths of a mile southeast of Bedford village. The excavations consist of four open pits, three closely adjacent ones on the upper part of the hill slope and one at a lower level. All the pits are elongate in a northeast-southwest direction, which probably represents the trend of the pegmatite dikes. The lower pit exposes the downward and northeastward continuation of the same pegmatite mass that is revealed in the southernmost of the upper-level pits.

The northernmost of the upper-level pits is about 50 feet wide, 100 feet long, and 35 feet in maximum depth. The two southern pits on this level are larger, being 100 to 150 feet wide, about 300 feet long, and about 50 feet in maximum depth. Most of the rock exposed in the central pit of the upper group is quartz, which is mainly white but here and there assumes a very beautiful rose tint. Some black tourmaline occurs in single crystals or radiating crystal aggregates in the quartz, and there has been some coating of fracture planes in the quartz with thin layers of black tourmaline. These thin coatings, in few places over one thirty-second of an inch in thickness, have plainly developed subsequent to the solidification and fracturing of the quartz and may be explained either as secondary depositions by surface waters percolating along the fractures or as a deposition by hot aqueous or gaseous solutions penetrating along the cracks in the pegmatite mass in the very latest stages of its solidification. Quartz with this black-tourmaline coating is unfit for commercial use and is discarded. The quartz seems to be associated with the feldspar in a wholly irregular manner. It forms most of the northwestern and southwestern walls of this quarry but in the southeastern wall is abundant only at the base, the upper parts of the wall being feldspathic. The feldspathic constituents of the pegmatite are best exposed in the other three pits, where they constitute a large proportion of the whole rock. The feldspar is of two principal varieties, one pink or flesh-colored and the other white. When examined under the microscope, the pink variety shows the optical properties of the feldspar microcline. The analyses of the pink spar (see Nos. 1 and 2 of the following table) show small amounts of soda and lime, but no soda or lime-soda feldspars were observed associated with the microcline in

the specimens examined. It is probable that part of the soda is chemically united with the potash in the microcline and that the feldspar is in reality a soda microcline. Analysis 4 of the table represents a pink microcline from the feldspar quarries at Bedford, Ontario, and is inserted for purposes of comparison.

Analyses of microcline feldspars.

	1.	2.	3.	4.
Silica (SiO_2)	65.95	65.85	65.33	65.40
Alumina (Al_2O_3)	18.00	19.32	20.96	18.80
Iron oxide (Fe_2O_3)	.12	.24	.71	Trace.
Lime (CaO)	1.05	.56	None.	None.
Magnesia (MgO)	Trace.	.08	None.	None.
Potash (K_2O)	12.13	14.10	10.65	13.90
Soda (Na_2O)	2.11		1.37	1.95
Loss on ignition				.60
	99.36	100.15	99.02	100.65

1. Pink microcline feldspar from quarry of Kinkle's Sons, Bedford, N. Y. Analysis by John C. Wiarda & Co.
2. Pink microcline feldspar from quarry of Kinkle's Sons, Bedford, N. Y. Bull. New York State Museum No. 93, 1905, p. 926.
3. Buff-colored microcline feldspar from quarry of Albert Hobby, North Castle, N. Y.
4. Pink microcline feldspar from quarry of Richardson & Sons, Bedford, Ontario. Analysis by Heinrich Ries, Cornell University.

The pink feldspar is in part pure and in part intergrown with quartz. This intergrowth consists of single crystals of quartz and feldspar penetrating each other in such a manner that on certain cleavage faces of the feldspar the quartz forms a peculiar pattern somewhat resembling the cuneiform inscriptions of the ancients. From this fancied resemblance to ancient writings the rock has been called graphic granite. There is every gradation from pure feldspar through coarse-grained graphic granite into fine graphic granite. The pink feldspar, pure or in intergrowth with quartz, generally occurs in somewhat irregular but sharply bounded areas within the general pegmatite mass. In the southernmost of the upper quarries these constitute about one-half of the whole pegmatite mass. A few of the smaller pink feldspar areas have perfectly straight boundaries which parallel the cleavage directions within the crystal. One sharply-outlined mass of pink feldspar 3 feet long by 1½ feet wide was bordered on all sides by white quartz. The larger masses are as a rule inclosed partly by pure quartz and partly by irregularly associated white quartz and white feldspar, in varying proportions, with a little pink feldspar, biotite, black tourmaline, beryl, etc. The white feldspar is shown by microscopic examination to be largely albite and constitutes the second important feldspar variety characteristic of this quarry. The parts of the pegmatite characterized by its presence are in a few places graphic granite, but for the most part show a very irregular texture and varying proportions of feldspar and quartz from point to point.

The mica of these quarries is mainly muscovite, which is commonly

associated not with the quartz but with the feldspathic portions of the deposit or may lie between feldspathic areas and areas of pure quartz. In places the mica "books" lie with their sides parallel to the quartz-feldspar contacts, but more generally they stand at right angles to these contacts. Few of them exceed 4 to 5 inches in diameter and almost all show the A structure and much "ruling." No plate mica was seen and the total amount of muscovite is hardly sufficient to make it worth while to save it for scrap mica. Being mainly confined to rather definite bands in the pegmatite, most of it can be readily separated from the highly feldspathic portions. It is not injurious chemically either in pottery or glass manufacture, but the thin elastic plates are difficult to grind to the requisite fineness.

Biotite (black mica) occurs in long, thin, lath-shaped crystals some of which reach a length of several feet though most are much smaller. Black tourmaline is associated mainly with the quartz, but is here and there present in the feldspathic parts of the pegmatite. Magnetite and garnet are present in few places, but no gem varieties of tourmaline or of beryl have been found. Columbite is present here and there in small crystals, as are some other rare minerals.

Three grades of feldspathic material are obtained from these quarries. "No. 1" is selected from the purer portions of the pink-feldspar masses and will probably run considerably less than 5 per cent in free quartz. Nos. 1 and 2 of the table are said to be analyses of the nearly pure pink spar and may be assumed to represent rather closely the composition of the "No. 1" spar, which is placed on the market. All of this grade is shipped in bulk. The "No. 2" feldspar produced at this quarry includes the coarser graphic intergrowths of pink feldspar (microcline) and quartz and also includes pegmatitic material rich in the white soda feldspar, albite. This grade is therefore higher in free quartz and in soda than the "No. 1." Both the "No. 1" and "No. 2" grades are used in the manufacture of pottery and must be entirely free from black mica, black tourmaline, garnet, and other iron-bearing minerals. The "No. 2" spar is not shipped in the crude state, but is ground at the quarries. A "No. 3" grade, made up mainly of the albite-quartz mixture with some of the finer grained pink graphic granite, is also ground at Bedford for use in glass manufacture. It is somewhat higher in quartz and soda than the "No. 2," and muscovite, biotite, and black tourmaline are not so carefully eliminated as in the "No. 1" and "No. 2" grades, these constituents not being so injurious in glass as in pottery manufacture. Microscopic examination of the "No. 3" spar shows the presence of free quartz, microcline (potash feldspar), and albite (soda feldspar).

The quartz from this quarry is all shipped in the crude state to the Bridgeport Wood Finishing Company at New Milford, Conn., where it is ground and used in the manufacture of a wood filler.

The grinding mill of Kinkle's Sons is located at the quarries and is similar in equipment to most feldspar mills elsewhere,[a] except that the spar as it comes from the chasers goes to a vibration separator, only the tailings being sent to the ball mills. For pottery spar this separator is provided with a 140-mesh screen, but in the preparation of spar for glass manufacture only a 60-mesh screen is required.

In one sample of the "No. 3" spar measured under the microscope no particles over 0.01 inch (0.25 mm.) in diameter were seen. Most of the material was under 0.002 inch in diameter and the finest particles were under 0.0001 inch.

The ground spar is usually shipped in bags. All of the material from this quarry and mill is hauled by team 5 miles to Bedford station, on the New York Central Railroad. The average price for the crude "No. 1" spar is about $5, for the ground "No. 3" spar about $6.50, and for crude quartz about $3 per ton, f. o. b. cars at Bedford station. The "No. 1" and "No. 2" grades for pottery use are shipped mainly to Trenton, N. J., and East Liverpool, Ohio, though small amounts have been shipped as far as Portland, Oreg.

HOBBY QUARRIES.

A small quarry owned by Albert Hobby, of Bedford, N. Y., and operated by Max Büresch, has recently been opened in the town of North Castle, near the west side of Mianus River, about 1½ miles southeast of the Kinkle quarry. The quarry is situated on a steep eastern hill slope and is about 100 feet wide, 150 feet long, and 40 feet in maximum depth. No exposures of the surrounding rocks were observed near the quarry. The pegmatite shows masses of pure feldspar 8 to 10 feet across associated with masses of pure quartz, some of which are 15 feet across. The quartz is in part white and in part a beautiful rose tint. There is almost no intergrowth of quartz and feldspar. The feldspar is buff colored and is shown by microscopic examination to be microcline (potash feldspar, probably containing a little soda). Its analysis is No. 3 of the table. Small and very thin plates of muscovite occur along some of the cleavage planes in the feldspar, but they are not abundant enough to affect the quality of the spar materially. Muscovite in larger plates is mainly segregated in somewhat irregular bands in association with black tourmaline in prismatic crystals that reach 1½ inches in diameter.

This quarry differs from the Kinkle quarry in the fact that the feldspar is practically all buff-colored microcline, and in the more complete separation of quartz and feldspar, graphic granite being apparently wholly absent. The present exposures cover only a small area, and it is impossible to predict the extent or uniformity of

[a] For description of grinding process see p. 387 of this bulletin.

the deposit. Mianus River is capable of furnishing ample water power for operating a grinding mill, and the materials could be carried by gravity down the hill slope to the mill. The material is hauled by teams 8 miles to Bedford station. Little material has as yet been marketed. It is unfortunate that this property is located so far from transportation lines.

A small quarry owned by Mr. Hobby and situated about one-half mile east of the Kinkle quarry is not now being operated and was not visited by the writer.

MICA, GRAPHITE, ETC.

MICA DEPOSITS OF WESTERN NORTH CAROLINA.[a]

By Douglas B. Sterrett.

INTRODUCTION.

Though one of the lesser minerals, mica is of considerable importance in the industrial world. It receives its most important application in the electrical industry. It is also used in the manufacture of stoves, lighting apparatus, wall papers, lubricants, paints, boiler coverings, fireproof apparatus, etc. About half of the mica consumed in the United States is of home production. The remainder is imported, chiefly from India, with smaller amounts of phlogopite, or "amber" mica, from Canada. The States contributing to the home production in 1905, in order of relative rank, are given by G. O. Smith[b] as North Carolina, Colorado, New Hampshire, Georgia, South Dakota, and New Mexico. Of the total production, amounting to $201,155, North Carolina is credited with over two-fifths. During some previous years this State has contributed over two-thirds of the domestic production.

The mica deposits of western North Carolina have been examined by several investigators in the interest of the State Geological Survey. The subject receives only brief treatment here, as it is expected that a nearly complete report will be prepared by the State Survey during the coming year. The present paper represents, in part, the results of field work by the writer, under the direction of the North Carolina Geological Survey, chiefly during the field season of 1906. Certain data used, however, were obtained in 1905 during the joint survey of

[a] Published by permission of the State geologist of North Carolina.

[b] Mineral Resources U. S., 1905, U. S. Geol. Survey, 1906, p. 1281.

the Balsam Mountain region, in parts of Haywood, Jackson, and Transylvania counties, by the Federal and State surveys. The writer wishes to express his appreciation of the aid rendered him by Mr. Arthur Keith in the preparation of these pages.

Active mica mining has been carried on in North Carolina for the last thirty-eight years, though with varying degrees of energy and success. The remains of ancient workings with crude stone tools around some of the better deposits give evidence of early mining by the aborigines or prehistoric people. The starting of the present industry is generally credited to Thomas L. Clingman, who had the Silvers mine opened in Yancey County in 1868. After taking out some good blocks of mica he was called away by other duties without disposing of them. The mica was brought to the attention of Heap & Clapp, stove dealers, of Knoxville, Tenn., who recognized its value and shortly after started work on this and other mines.

It is claimed that the earliest mica mining in North Carolina was done in Jackson County in 1867 by a Mr. Person, of Philadelphia. In 1858 a specimen of mica from Jackson County was exhibited at the State fair in Columbia, S. C., by D. D. Davies. Nine years later, after the value of mica was better recognized, Mr. Person came to Jackson County and started operations on numerous prospects known to Mr. Davies.

After a number of years of depression due to low market values at the time when India mica was imported into the country in large quantities, the production is again increasing. Especially during the last two years has the industry gained strength, and at the present time many companies and private persons are examining or developing old and new mines and prospects.

For more detailed information on mica than it is possible to give in a brief report of this nature, the reader is referred to the following publications:

Pratt, J. H. The Mining Industry in North Carolina, annual publication of North Carolina Geol. Survey, 1900–1904.

Production of mica in the United States: Mineral Resources for 1905 and several years preceding, U. S. Geol. Survey. Especial attention is called to the report by J. A. Holmes in the volume for 1898 (Twentieth Ann. Rept., pt. 6, continued, 1899, pp. 691–707).

Ells, R. W. Mica deposits of Canada: Mineral Resources of Canada, 1904, Canada Geol. Survey.

Cirkel, Fritz. Mica, Its Occurrence, Exploitation, and Uses, Mines Branch, Dept. Interior, Canada, 1905.

Colles, G. W. Mica and the mica industry: Jour. Franklin Inst., Philadelphia, vol. 160, 1905, pp. 275–294. Reprinted in book form in 1906.

DISTRIBUTION AND GENERAL CHARACTER.

Mica-bearing pegmatites occur over a wide area in North Carolina, roughly bounded by the State lines on the northeast and southwest. This area extends about 50 miles southeast of the Blue Ridge and northwestward nearly to the Tennessee line. (See fig. 13.) Mica mining has been carried on in eighteen or more of the counties included in this area. The largest producers have been Mitchell, Yancey, Macon, Jackson, Haywood, Ashe, and Cleveland counties. Good deposits have been discovered in other counties, and some have yielded considerable mica.

Most of the mica mined comes from three belts in the western part of the State. These may be called the Cowee-Black Mountain belt,

FIG. 13.—Map showing areas in North Carolina in which mica has been mined.

the Blue Ridge belt, and the Piedmont belt. The first of these extends nearly through the State, parallel to and near its northwestern border. It lies northwest of the Blue Ridge and includes part of Macon, Jackson, Transylvania, Haywood, Buncombe, Yancey, Mitchell, Watauga, and Ashe counties. The second belt follows the Blue Ridge through the State and extends several miles to the southeast among the foothills of the ridge. It is of relatively small importance as compared with the other two. The Piedmont belt lies wholly in the Piedmont Plateau, southeast of the Blue Ridge, mainly in Cleveland, Lincoln, Burke, and Stokes counties. Commercial mica deposits have not been found in unbroken succession through the whole length of any one of these belts.

The quality of the mica obtained from different localities varies considerably. In general it may be said that the mica of the Cowee-Black Mountain belt is chiefly clear and of light color (as a rule "wine" or "rum"). That from the Blue Ridge belt has a dark smoky-brown color and much of it is more or less "specked." In much of the Piedmont belt the mica is of good quality and similar to that of the Cowee-Black Mountain belt. Of course there are exceptions to these characteristics, in part connected with geologic conditions which will be mentioned in another place (p. 407).

The Cowee-Black Mountain mica belt is in the heart of the Appalachian Mountains. The deposits lie at various elevations between 2,000 feet above sea level and that of the highest mountains, or over 6,500 feet. Some are high up on the rugged slopes, where the soil covering is thin. Others are on the gentle slopes of the valleys, covered by deep residual clays. Much the same could be said of the Blue Ridge belt, though the elevations are not so great. In marked contrast with the high relief of the mountain region that includes these belts is the topography of the Piedmont Plateau southeast of the Blue Ridge. The general elevation in the mica-bearing areas of the plateau belt is from 1,000 to 1,500 feet above sea. Though typically a plateau, it is more or less dissected by river and creek valleys 200 or 300 feet deep.

The rainfall in western North Carolina is heavy, and, as the climate is not severe, vegetation flourishes, and large areas are covered with dense forests. The residual soil covering due to rock decay is in many places very thick, especially where the slopes are gentle and the removal of decomposition products is slow. These features combine to make the discovery of mica deposits difficult.

GENERAL GEOLOGY.

The mica-bearing pegmatites of North Carolina are found chiefly in rocks of Archean age, and are practically confined to mica, garnet, cyanite, hornblende, and granite gneisses and schists. Other rocks in the region are granites, diorites, and peridotites, also of Archean age, as well as younger granites, volcanics, and sediments. The metamorphism, folding, and faulting of the gneisses and schists have been extreme. In most of the Archean rocks it is difficult to determine the original nature of the formations, since much of the sedimentary bedding and igneous texture has been destroyed by mashing and recrystallization.

The majority of the mica deposits occur in two formations as mapped by Keith,[a] namely, the Carolina gneiss and Roan gneiss. The Carolina gneiss includes most of the gneisses and schists mentioned above that are not hornblendic in composition. The Roan

[a] Geologic Atlas U. S., Asheville (116), Cranberry (90), Mount Mitchell (124), Nantahala (143), Pisgah and Roan Mountain folios, U. S. Geol. Survey.

gneiss is composed of hornblende gneiss and hornblende schist with smaller beds of mica gneiss and mica schist included. Large areas of the other rocks mentioned above are mapped as separate formations. These are principally granites and granite gneisses of Archean age. In the mica regions by far the most important formation is the Carolina gneiss. It extends from the northwestern side of the Cowee-Black Mountain belt to and beyond the southeastern side of the Piedmont belt. In a northeast-southwest direction it extends far beyond the State boundaries. The age of the Carolina gneiss is greater than that of any other formation in the region. Igneous rocks of later epochs have been intruded into this gneiss, which has been gashed and cut by them into irregular-shaped masses, in many places forking out into long tongues or occurring as long, narrow streaks in the intrusives, or vice versa. This feature is common to both the granite intrusives and the Roan gneiss, which is the next oldest formation of the region. Rocks of still later age, as Cambrian sediments, have been metamorphosed into gneiss and schist and folded with the older formations by movements associated with the Appalachian uplift. The Carolina and Roan gneiss formations have been interbanded with and cut at all angles by numerous streaks of granitic or pegmatitic material. These range from a fraction of an inch upward in thickness, and locally pass into mica-bearing pegmatites. In some places pegmatization is so thorough that mica gneisses become strikingly like granite gneisses. This is especially characteristic of the Carolina gneiss in the Piedmont region.

The study of the geology in this region is exceedingly difficult, because the rocks have been so intensely folded, faulted, and metamorphosed. The enormous amount of erosion the region has undergone and the present depth of atmospheric decomposition also complicate the task.

OCCURRENCE OF MICA.

Mica deposits of commercial value in this State are confined to pegmatites. These rocks vary considerably in form, some being typically lenticular in shape and others more or less persistent in length. The lens-shaped bodies are generally conformable with the schistosity of the inclosing rock. They may lie in the same line of bedding or schistosity and be connected by smaller streaks or stringers of pegmatite or by mere seams in the rock. Many of them, on the other hand, lie in planes of schistosity more or less separated from one another and form parallel or overlapping bodies. In cross-section some of these lenses are short and bulky, with a length only two or three times the thickness; others are long and tapering, and may constitute simply a bulge in a sheet of pegmatite. In most places the schistosity of the inclosing rock bends around the lenses.

Some of the more persistent pegmatites occupy straight fissures that hold their direction for some distance. Elsewhere they are folded with the country rock or bent and twisted into various shapes. Many are more or less conformable with the bedding of the gneisses and schists. In the latter case they are, in a large measure, subject to the deformations of the country rock. In many places, however, the pegmatites are conformable for some distance, and then branch out, cutting from one layer to another across the bedding. Locally there is an elbowing or bulging out on one wall, without a similar irregularity on the other wall of the pegmatite. It is not uncommon for pegmatite masses to cut across the country rock for long distances.

Though pegmatites have been worked for mica in regions of hornblende gneiss and hornblende schist, where they are directly associated with those rocks, the majority of the deposits are in small biotite-gneiss or schist masses included in the hornblende areas. Where the pegmatite is in contact with hornblende gneiss, the latter may be highly biotitic.

Pegmatites occur in irregular masses, streaks, lenses, augen, or balls, some of them having no visible connection with other pegmatite bodies. They range from a fraction of an inch up to many yards in thickness. The limit of size below which they can not be profitably worked for mica might be placed arbitrarily at from 1 to 2 feet for rich and regular "veins." In the very large pegmatites the mica is not in general evenly distributed through the mass, but is richer in one portion than another, so that the entire bulk of the rock does not have to be removed in mining. The irregularities of pegmatites and the consequent difficulties in mining mica from them are well illustrated in road cuts or similar excavations where pegmatized gneiss or schist has been cut into. The lenticular shapes, pinching and swelling, crumpling, folding, and faulting to be observed in these cuts are found to be nearly duplicated in larger pegmatites opened for mica. As stated before, these smaller masses may grade into those containing mica of commercial value. Here and there the two can be seen at the same locality.

Horses or inclusions of wall rock are common in pegmatites. Some of them are in the form of bands or sheets parallel to the walls, and the schistosity of these bands is also parallel to the walls. They range from an inch or two up to a couple of feet in thickness and their length may be many times their width. Elsewhere they occur as irregular-shaped masses from a few inches up to several feet thick. If the bedding has been preserved, it may lie at any angle with that of the inclosing wall rock. In some places the horses are partially pegmatized by streaks of pegmatite ramifying through them and the development of considerable feldspar and quartz through their mass.

In such places no sharp line can be drawn between the point where the pegmatite ceases and original horse begins.

Pegmatite is closely allied to granite in composition. As in granite, the essential constituents are feldspar and quartz, with more or less mica and other accessory minerals. Though hornblende is a rather common mineral in granite, it is less so in pegmatite. Orthoclase or microcline are the most common varieties of feldspar found in pegmatite. In many places, however, a variety of plagioclase, either albite or oligoclase, makes up part or all of the feldspar component. The feldspar occurs in masses and rough crystals with a diameter of several feet. In the old Mart Wiseman mine near Sprucepine, Mitchell County, orthoclase crystals 2 by 4 feet and larger have been cut through. From their whole rectangular cross section, as exposed in the walls of the tunnel, a simultaneous reflection of light is obtained from the cleavage faces.

Quartz assumes various forms and positions in the pegmatite. In many places it bears much the same relation to the feldspar and mica as in granite, the three minerals being thoroughly mixed with one another; but the individual grains are many times larger than in ordinary granite. Not uncommonly the quartz and feldspar assume a graphic-granite texture in a portion of the pegmatite. Another common feature is the occurrence of large separate masses of quartz occupying various positions in the pegmatite. Such quartz masses may be irregular in form and but little influenced by the shape of the pegmatite or inclosing walls. Generally, however, they occur in bands or sheets lying parallel to the walls. There may be one or more of these quartz bands constituting varying proportions of the pegmatite. Their thickness ranges from a fraction of an inch up to 6 or more feet. Many of them are lenticular in shape, the length varying from four or five to twenty or more times the thickness. In numerous places these quartz streaks or veins are persistent through the whole length of the pegmatite exposed. Some inclose feldspar or mica bodies; others do not. The quartz of these segregations is massive and generally granular, though locally crystallized. In the latter case it may be translucent or clear and of a dark smoky or light color. It is generally rather pure and does not contain feldspar or mica in any quantity.

Muscovite is the common mica of pegmatite and is the only variety mined in North Carolina. Biotite occurs in some quantity in a few deposits and in smaller amount in many others. Where muscovite and biotite occur together in a deposit, the muscovite is generally clear and of good color. It is not unusual for the two to occur in intergrown crystals with a common cleavage plane. Again, mica from deposits in rock formations where the ferromagnesian minerals are abundant, as hornblende or biotite gneiss and schist, is generally

found to be clear and of light color. Where the pegmatite is closely associated with or occurs in granite with a paucity of the ferromagnesian minerals, the mica is generally of dark color and much of it "specked." The true color of mica is best observed in sheets from one-sixteenth to one-fourth inch in thickness when examined in transmitted light.

The mica occupies various positions in the pegmatite. Where the rock has a typical granitic texture, the mica may be found evenly distributed through it. More commonly the larger crystals will be found either in clusters at intervals through the "vein," in places connected by streaks of small crystals, or collected along one or both walls of the pegmatite, with some of the crystals partly embedded in the wall rock. Where there is a quartz streak within the pegmatite, the mica occurs on either or both sides of it, being in places partly embedded in the quartz or occupying any of the positions noted above in the remaining portion of the pegmatite, which generally is composed largely of feldspar.

ASSOCIATED MINERALS.

Over forty different minerals have been found in the pegmatites of North Carolina.[a] Besides muscovite mica, several others of commercial importance are found, including quartz in large masses, feldspar in considerable quantity, kaolin in large deposits, beryl of several gem varieties, zircon, uranium minerals carrying radium, samarskite, and columbite. Most of the rare minerals, as gem beryl, columbite, those of uranium, etc., are found in Mitchell and Yancey counties; though beryl of gem quality is found also in many other counties. The beryls from the pegmatites have furnished handsome gems, as emerald, aquamarine (sea green and blue), and the golden variety. The potash feldspar removed in mica mining should prove of value if shipped to manufacturers. Kaolin results from the decomposition of the feldspar of the pegmatites by weathering. In the majority of the pegmatites of North Carolina that have been opened for their valuable minerals the feldspar is found to have partially or entirely altered to kaolin from the outcrop down to depths varying from a few to 100 feet or more. In this way valuable deposits of kaolin have formed.

DESCRIPTION OF MINES.

MILTON ENGLISH AND NEIGHBORING MINES.

The Milton English mine, about 1 mile northeast of Plumtree, Mitchell County, furnishes one of the most typical examples of pegmatite lens formation known. The pegmatite lies in one of the

[a] Pratt, J. H., Mining industry in North Carolina in 1901: Economic Paper North Carolina Geol. Survey No. 6, 1902.

smaller biotite-gneiss bodies included in the large area of hornblende gneiss which forms the country rock of the region. The rocks as exposed in the mine are approximately horizontal, with only a few gentle monoclinal folds dipping southward.

A tunnel has been driven in over 450 feet in a southerly direction. From this drifts have been run off both to the east and the west for distances varying from 25 to 60 feet. The main tunnel was carried back by a series of rooms, some being about 25 feet wide, where the "vein" was found sufficiently rich. The size and shape of these rooms depended on the pegmatite lens that was removed for mica as they were being made. In some places all of the pegmatite had been removed on one side of the room or the other. In others, however, a streak a few inches thick was left in the walls, showing where the lens had pinched down from several feet (the height of the room) to a few inches. The structure of the pegmatite is strikingly illustrated in the walls and faces of the workings, where cross sections of the lenses can be seen. Some are 6 to 10 inches thick and a couple of feet long, others are of much greater thickness (up to 5 or 6 feet) and of proportional or even greater length. These lenses overlap or lie parallel to each other. Many of them lie in the same strata of the gneiss, though separated by several feet. A thin seam or parting, locally containing a little pegmatite material, can generally be traced between two such lenses. Here and there the pegmatite occurs in sheets or streaks, which in places bulge out into lenticular form. These streaks may pinch down to mere threads, but when followed a little way open out into other lenses. The full thickness of the belt of overlapping and parallel pegmatite lenses and streaks is generally under 8 feet. The mica gneiss curves around swells and bulky parts of the lenses.

From the mouth of the tunnel the pegmatite outcrop has been traced both to the east and the west for some distance around the contour of the mountain side. A diabase dike, called "the iron bar" by the miners, follows the pegmatite back as far as development work has been carried. It is very irregular, appearing in one place cutting into the pegmatite and then not seen again for some distance.

The texture and composition of the pegmatite are those of very coarse granite. The three constituent minerals are thoroughly mixed and have separated out in large masses. Even in lenses only 10 inches thick mica crystals 5 or 6 inches in diameter have been found. The quality of the mica is excellent. The color is a clear light "rum" when the sheets are about one-eighth inch thick. The lamination is perfect, and beautiful sheets for glazing purposes can be obtained. The yield for the amount of rock removed is satisfactory and contains a fair proportion of larger sizes.

Other mines have been opened to the southeast and east of the Milton English, apparently in the same formation. At the Johnson mine, nearly 2 miles to the southeast, the pegmatite is included in a hornblende gneiss, lying nearly flat, biotitic near the contact and conformable with it. It is sheetlike in form, pinching down to a few inches and beyond swelling to several feet.

McKINNEY OR POWDERMILL CREEK MINE.

The McKinney is a new mine, about 3 miles northwest of Plumtree, on the north slope of a mountain south of Powdermill Creek. The work consists of an open cut nearly 100 feet along the strike of the "vein" and not over 15 feet deep in any part. Only the width of the pegmatite has been removed. This rock lies in a biotite-gneiss streak, a few yards north of its contact with the hornblende-gneiss formation, which is the country rock of the region. The pegmatite is conformable with the gneiss and strikes due east at the west end of the cut and about N. 80° E. in the eastern part. The dip is about 80° S. The average width is about 6 feet, though it increases to 8 feet or more near the middle of the cut. At one point, near the west end, the south wall elbows out, causing the pegmatite to pinch abruptly from 6 feet down to 4 feet. In general, however, the variations in size are more gradual. The pegmatite has been traced by prospect pits for some distance farther east.

The texture of the pegmatite is that of coarse granite, except for a width of a few inches along the contact, where it is very fine grained and of dark color, thus being in marked contrast with the rest of the mass. The feldspar is chiefly a plagioclase. The mica is generally disposed near one wall or the other, though some large blocks occur nearer the middle of the "vein." It has a rather dark brown color and part of it is somewhat "specked." It is fairly plentiful, however, and blocks of good size are frequently obtained.

BIG RIDGE MINE.

The Big Ridge mine is about 6 miles east of south of Waynesville, Haywood County, high up on the southwest side of Lickstone Bald, at an elevation of about 4,500 feet. The mine is equipped with air drills and a steam pump. The mica-bearing pegmatite is conformable with the mica-gneiss country rock, and is folded with it into an anticline, the axis of which strikes about N. 80° E. and pitches 20° or more into the mountain side. The angle of the fold is not sharp, yet the legs dip about 45° a few rods from the axis. The workings consist of tunnels and drifts along the pegmatite, with stopes and raises between. On the north leg of the fold the "vein" has been removed for a depth of about 300 feet, but on the south it has been worked

for only about 100 feet. The pegmatite is fairly regular in thickness and would probably average 8 feet through a large part of the mine. In certain places where the full width of the "vein" had been removed rooms 12 to 15 feet high were left. The greater part of the pegmatite has a coarse granitic texture. A peculiar graphic-granite texture has been observed, in smaller portions of the pegmatite, caused by a parallel orientation of biotite plates in a feldspar-quartz matrix. A thin section cut from a piece of this nature showed, under the microscope, a semimicrographic arrangement of quartz in feldspar crystals. The feldspar is largely albite. A large amount of biotite, probably amounting to one-fourth or one-third of all the mica contained in the "vein," is found with the clear mica. In places the two form intergrowths with one another. Apatite, hornblende, and garnet are found as accessory minerals. The mica is of clear, light "rum" color and excellent quality. The mine has been worked for many years and has been a good producer. It is often closed during part of the winter, as it is found difficult to keep up sufficient steam to run the air compressor at such an elevation during the cold weather.

CATTAIL BRANCH MINE.

The Cattail Branch mine is near the head of Cattail Branch, in Yancey County, about 5,500 feet above sea level and nearly a mile southwest of Celo Mountain, the north end of the Black Mountains. It was discovered about 2 years ago by Silvers & Son and B. Rolland, all of Yancey County. The developments consist of open cuts at three different points on the outcrop. The country rock is biotite gneiss. Near the pegmatite it is much flexed and folded, striking northeastward with nearly vertical folds. The pegmatite is in the form of an inclined trough with a horseshoe or U-shaped cross section. The bottom of the trough pitches about 55° SW. and cuts directly across the country rock. The sides are nearly vertical and, at a little distance from the bottom of the trough, conform in a general way with the strike of the country rock. The thickness of the pegmatite varies from 3 feet in the curve of the horseshoe to 20 feet or more some distance out from the curve. This includes horses or tongues of wall rock around which the pegmatite has forked. About 30 feet southwest of the curve the northwest arm is nearly 25 feet thick, the greatest thickness exposed. The "vein" must have bulged out abruptly to attain such a thickness at this point. It contains mica-gneiss bands or horses, from a few inches up to a maximum in one place of several feet in thickness, and oriented parallel to the walls. The southeast arm shows a similar bulging, being about 12 feet thick at a distance of 25 feet from the curve.

The texture of the pegmatite is very coarsely granitic. The larger portion of the mica is found in the interior of the pegmatite, though some occurs scattered along the walls. The quality is excellent and the color a beautiful "rum." The yield in larger sizes is good, and smaller sizes are plentiful.

THORN MOUNTAIN MINE.

The Thorn Mountain mine is on the south side of Thorn Mountain, about 3 miles south of Wayah Gap, in the Nantahala Mountains, Macon County. There are two mines about a quarter of a mile apart on this mountain. The one chosen for description is sometimes called the No. 2 mine. The work consists of a good-sized open cut carried back about 40 feet on the strike of the pegmatite, and about

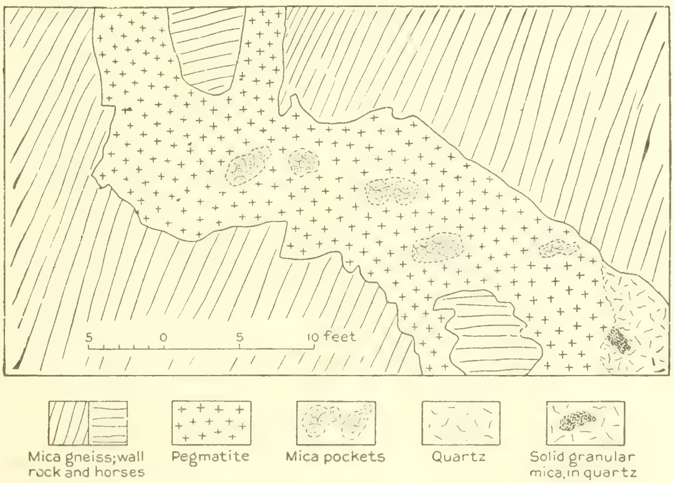

FIG. 14.—Section across pegmatite at Thorn Mountain mine, Macon, county, N. C.

25 feet deep at the farther end. The country rock is pegmatized mica gneiss, which strikes about N. 50° E. and has a high northwest to vertical dip. The pegmatite is from 10 to 15 feet thick, and cuts the gneissic country rock with a strike of about N. 25° E. and a dip of 50° SE. (See fig. 14.) At least one horse of mica gneiss is included in it and exposed near the bottom of the cut. This horse is a large one, with its schistosity turned at an angle to that of the wall rock. In the face of the cut, just below the top, the pegmatite either forks or, more probably, includes another horse of wall rock. The schistosity of this inclusion is also out of parallel with that of the walls. These horses are even more highly pegmatized than the country rock, and the lower one has a very irregular outline.

The texture of the pegmatite is that of very coarse granite. The mica does not seem to be confined to any one portion, but is found in

bunches or pockets of crystals at varying intervals through the mass. It is said that in mining often several feet of barren "vein" would have to be removed before one of these pockets was encountered. They generally yielded a good quantity of mica, however. In the bottom of the cut on the southeast side a mass of quartz had been laid bare, but it was not sufficiently exposed to determine its relation to the rest of the pegmatite. An irregular band of solid mica composed of an aggregate of small crystals, one-eighth to one-half inch or more in diameter was included in this quartz. It was 6 to 10 inches thick and 8 feet long. A little biotite is found with the muscovite at this mine. The two are in places intergrown, and in one specimen seen a sheet of black mica inclosed a rhombic-shaped plate of clear mica. The latter had very much the appearance of a fancy window in a dark wall. A small amount of pyrrhotite carrying a little chalcopyrite is scattered through this quartz in lumps up to half a pound in weight.

This mine has not been worked for several years. The "vein" material that had to be removed was found to be exceedingly hard. The distance of the mine from any settlements made it difficult to obtain labor. The mica was reported to be fairly plentiful, however, and this combined with its light color and excellent quality ought to equalize any disadvantages due to location.

MINES IN THE WAYAH BALD REGION.

Four mines have been opened in the Nantahala Mountains on the east and northeast side of Wayah Bald, Macon County. These are the Turkey's Nest, Lyle Cut or Evans, Wayah Bald, and Raven Cliff. All but the Raven Cliff were examined, and since they have so many features in common, a description of one with reference to the other two will answer for all three. The Lyle Cut has been chosen for description. It has been worked by an open cut the width of the pegmatite and about 40 yards back into the side of the ridge leading eastward from Wayah Bald. The depth is nowhere over 35 feet.

The country rock is mica gneiss, which strikes N. 80° E. and dips 60° NW. The pegmatite cuts across the gneiss with a strike of N. 40° E. and a dip of about 70° SE. It is 7 feet wide in places, but pinches down to about 3 feet at the entrance to the cut. These variations in thickness are rather gradual and the deposit appears to be very regular. The strike and dip remain uniform as far as the rock is exposed in the cut. A persistent quartz streak of variable thickness and continuity occurs within and near the middle of the pegmatite. It varies from 10 inches up to 2 feet in thickness, and is present in the full height of the pegmatite exposed in the face of the cut. It has a peculiar banding parallel to its direction and the walls of the pegmatite. In hand specimens the texture is granular and the banding

appears as alternating portions of more or less translucent and white quartz. Small mica plates lie in certain streaks or seams parallel to this banding. Under the microscope a thin section proved to be almost entirely composed of rather fine-grained quartz. The grains are angular and fit somewhat closely together. Some of them show evidence of moderate strain. Between crossed nicols a slight banding is apparent in certain directions by the extinction of the quartz grains. Parallel to this banding are two streaks of minute black particles, probably magnetite. These lie chiefly between separate grains of quartz, though some are included in the quartz grains. The quartz contains many inclusions. Some of them seem to be irregular cavities, with or without gas; others have a reddish color, and may be iron oxide which has worked its way from the pores between the grains into the cavities in the quartz.

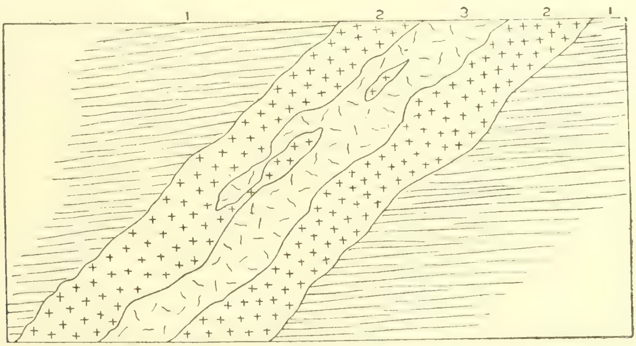

FIG. 15. Pegmatite, 2½ feet thick, at Wayah Bald mine, Macon County, N. C. 1, Wall rock (mica gneiss); 2, pegmatite, mostly feldspar, quartz, and mica; 3, quartz.

The mica was reported to be plentiful in the feldspar-quartz streak between the quartz band and the wall rock. The color is a beautiful "rum" and the quality excellent.

In the other two mines the pegmatite cuts the mica-gneiss country rock, as in the Lyle Cut. There is also a regular quartz vein within the pegmatite. The mica occurs in a matrix consisting mostly of feldspar with some quartz, between the quartz band and the walls. In the Wayah Bald mine the quartz forks in one place, nearly inclosing a small mass of feldspar (see fig. 15), and in another part it completely envelops a mass of feldspar 3 or 4 inches thick. Banding of the quartz was not observed in the Wayah Bald mine. Both mines produce "rum"-colored mica of the same excellent quality as that of the Lyle Cut.

All are old mines except the Wayah Bald, which is the only one that has been worked recently. It shut down, however, in the fall of 1906.

HORACE THOMPSON MINE.

The Horace Thompson mine is about 3½ miles northeast of Fallston, in Cleveland County. It has been opened by half a dozen shafts with considerable tunneling from them. Much material has been removed, and owing to the decomposed nature of the rock formations and the probably scant timbering used most of these workings have fallen in and the ground above them has subsided several feet. The openings are within an area about 60 yards east and west by 20 yards north and south. The country rock is garnetiferous gneiss and schist. Cyanite is another important constituent in parts of it. The garnets, which are up to 1½ inches in diameter, weather out in the soil near the mine. The products of weathering consist chiefly of clay through which abundant fragments of hematite and tufts of cyanite impregnated with hematite are scattered. The strike of the rock near the mine is mostly east and west, swinging to northwest in places, and the dip is nearly vertical. In two of the shafts with their tunnels on the north side of the deposit (not yet fallen in) there were quartz ledges and streaks in the large kaolinized feldspar formation exposed. Blocks of mica several inches in diameter had been left in the roof of one of these tunnels lying in the feldspar between the wall and one of the quartz masses. Small blocks were included in the quartz itself. It seems probable that this pegmatite formation is limited in extent, for an opening made about 20 yards east of the main workings exposed a small pegmatite body 2 or 3 feet thick with a northwest strike, thus cutting across the direction in which the main mass appeared to be running.

This mine has produced a large amount of good-sized mica. The color of the mica is clear "rum" and the quality excellent. The same may be said of the majority of the mines of this part of Cleveland County and Lincoln County adjoining. Quartz ledges are other features common to many of the mines of this section. The difficulties encountered in working the Thompson mine are found in nearly all the mines of this region, namely, large amounts of water to handle, formations that require much timbering, and the apparent pinching out of the mica-bearing rock in one or more directions.

COWARD MOUNTAIN MINE.

The Coward Mountain mine is near the top of the south end of Coward Mountain, on the north side of the Caney Fork Valley, Jackson County. The notable features are the occurrence of sheetlike horses of wall rock and streaks of quartz parallel to the walls of the pegmatite. The country rock is hard garnetiferous mica gneiss, somewhat schistose near the contact with the pegmatite. The latter is about 10 feet thick and strikes about N. 45° E., with a dip of 75° NW.

Where seen near the surface, it is nearly or quite conformable with the inclosing rock. Quartz is the predominant mineral and occurs in veins and streaks parallel to the wall rock. These streaks range from 1 or 2 inches up to a couple of feet in thickness. Feldspar is nowhere very abundant in the pegmatite and is confined chiefly to a streak 2 or 3 feet thick near the hanging wall, where with quartz and mica it forms the "vein." Horses or sheets of schistose wall rock are included in the pegmatite in several places. They range from 2 or 3 to several inches in thickness. These horses, together with the quartz bands and mica streak, all parallel to the walls, give a marked banded structure. Such inclusions of sheetlike horses of wall rock and veins of quartz in parallel position are not uncommon in this region.

This mine has not been worked in recent years. The developments consist of a shaft on the "vein" reported to be 100 feet deep, with sufficient open-cut work at the surface to give working room on the mountain side. The mica is of a clear "rum" color, and to judge from smaller pieces seen, of good quality. Some biotite is found with the clear mica. A little sulphide of iron is scattered through the "vein" and wall rock.

COX & DAVIES MINE.

The Cox & Davies mine is about three-fourths of a mile south of Cullowhee, Jackson County, on the point of a ridge, 200 or 300 feet above the road. The developments consist of open cuts, shafts, and tunnels, mostly in bad repair. There are two parallel "veins" about 70 feet apart, and both have been worked for about 100 yards across the top of the ridge. The mica-gneiss country rock strikes about N. 80° E., with a southerly dip. The pegmatite masses conform with this in a general way, though they cut the gneiss in places.

A tunnel on the north "vein" was examined for about 150 feet into the hillside. The thickness of the "vein" was in the main from 2 to 4 feet, but in places it swelled to 6 or 8 feet. At one point the pegmatite was warped, the strike shifting from N. 70° E. to S. 80° E. and back again, with a varying southerly dip. It cut across the mica gneiss, which at this point had a strike of N. 45° E., and a vertical dip. Quartz was exposed only in smaller masses and ledges in this tunnel. The feldspar was partly kaolinized and easily removed in mining. Quartz was found to be more plentiful in the south "vein." In one of the tunnels still open a quartz streak nearly 2 feet thick was exposed in the roof and extended some distance back. Both veins have been more or less "ground-hogged" through their whole length. This has been done mostly by petty leasers, who did not care what happened to the mine after their leases expired. Mica of excellent quality and in large quantity has been removed from each vein. The color is a fine clear light "rum" or "wine," and the mica is said to have brought always the highest prices.

CHINK KNOB PROSPECT.

South of Chink Knob, near the main road through Canada Township, Jackson County, is a small opening several feet deep, which is described here only because of the peculiar type of pegmatite exposed. The country rock is mostly mica gneiss, with smaller granitic masses included. These are doubtless outliers of the larger intrusions of granite in the neighborhood. Some of them assume a pegmatitic texture in places. The prospect reveals a vein of pegmatite from 3½ to 4 feet wide. (See fig. 16.) It strikes about N. 5° W. and dips from 75° to 80° E., cutting one of the coarse granite masses already mentioned. The mica-gneiss country rock a few rods from the prospect had a strike of N. 55° E. and a dip of 50° NW.

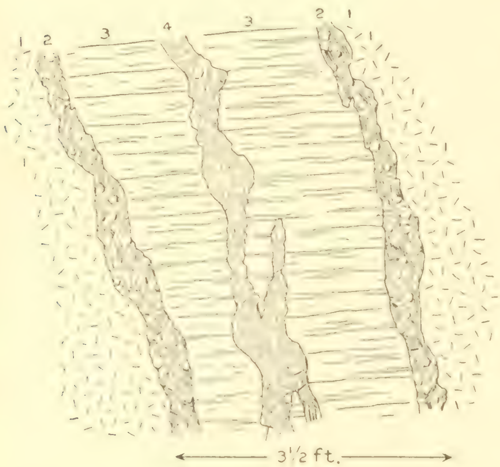

FIG. 16.—Section of pegmatite at mica prospect near Chink Knob, Jackson County, N. C. 1, Coarse granite; 2, mica and feldspar; 3, quartz, jointed; 4, feldspar with little mica.

The vein is composed largely of quartz. On each side and down through the interior of this quartz there is a streak or band of feldspar and mica. The interior band consists chiefly of feldspar with a small amount of mica, but in the bands between the walls and the quartz mica is probably in excess of the feldspar. The quartz is massive and of a dark smoky color. It has a sheety columnar jointing about normal to its walls, probably caused by later rock movements. The mica is mostly wedge-shaped and "A." It is of a dark smoky color and partly "specked." Blocks from 3 to 5 inches across were probably the largest found during the prospecting.

ADAMS MINE.

The Adams mine, 1½ miles southeast of Webster, Jackson County, is unique. A small granite dike from 4½ to 8 feet thick cuts sharply across the mica-gneiss country rock. The dike strikes N. 25° to 30° W. and dips from 55° to 70° NE.; the mica gneiss has about a northeasterly strike, with a dip varying from nearly vertical to 70° SE. This granite is rather fine grained and light gray to nearly white in color. It has an even texture and shows no banding. The dike has been traced over 100 yards along the strike by prospects, openings, and tunnels. On each side of the granite throughout its exposure

there is a pegmatite streak from 1 to 2 feet thick. (See fig. 17.) In some places this pegmatite is made up chiefly of mica; in others feldspar with some quartz is equally important. The contact between the pegmatite and granite is irregular and not sharp. Many of the mica crystals, especially those near the contact with the mica gneiss, have their cleavage planes normal to the walls of the pegmatite. They do not exhibit any other definite orientation, however. The feldspar has been kaolinized to some extent near the surface. The mica blocks are chiefly small (under 4 or 5 inches in diameter). They have a clear "rum" color, but many are damaged by clay stains between the laminæ. They are plentiful, however, and yield much punch and scrap material.

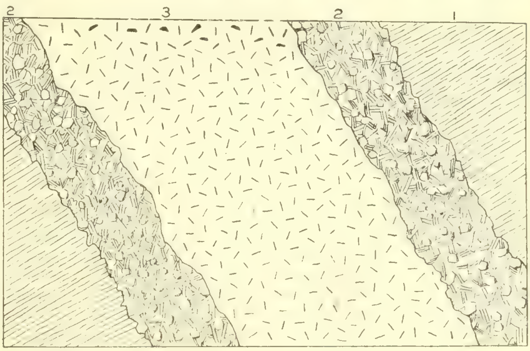

FIG. 17.—Section of pegmatite at Adams mine, 1½ miles southeast of Webster, Jackson County, N. C. 1, Wall rock (mica gneiss); 2, pegmatite, mostly mica; 3, granite, rather fine grained. Distance from wall to wall, 7 feet.

A pretty example of faulting is exposed in this mine. The mica streak on the southwest side of the granite has been brought nearly opposite that on the northeast side by a fault with an 8-foot throw. This fault strikes a little east of north and is nearly vertical. The formations on the east side of it have slipped to the north a few feet, or vice versa.

MINING AND TREATMENT OF MICA.

The methods employed in working most of the mines are simple. Open cuts are started on the outcrop, followed by shafts or tunnels when the "vein" is found sufficiently rich. In some of the larger mines power drills and steam pumps are employed and development proceeds rapidly. As a rule, however, simple tools are used, such as pick and shovel in decomposed formations and hand drills where hard rock is encountered. Dynamite is used chiefly in breaking down hard rock. The "vein" is worked out by shafts (generally inclined), tunnels, drifts, winzes, and stopes. The minimum of timbering is used, and pillars are left only where absolutely necessary. The workings generally have a very irregular shape, since they follow the mica streaks or pockets wherever found. Too often, in the past especially, the deposits have been so irregularly worked that the term "ground-hogging" has been applied to the methods employed. "Ground-hog" workings consist of irregular openings at the surface,

shallow shafts, and small crooked tunnels, scarcely large enough for a man to work in. The term might also be appropriately used to describe the irregular stopes made by "jayhawkers" and petty leasers in underground workings. These people cut down all the mica-bearing material available and leave the waste to accumulate in the mine until further work is difficult or impossible.

Some of the mines are located in rather inaccessible places, to which tools and provisions have to be packed on men's shoulders, and from which the mica is brought away by the same methods. As the needs of the mountaineer and the variety of tools required are small, even these mines can often be operated at a profit.

At most of the mines blacksmith forges of suitable size to meet the requirements are set up so that drills and tools can be sharpened and other shop work done. Each mine generally has a storage bin or house where the mica is kept and sorted over before selling or hauling to trimming establishments. At some mines the output is sold in the rough. At others it is split and sized either with or without trimming off the rough corners and edges. Part of the production is shipped to the manufacturers after rough trimming and sizing, and the remainder is prepared for the market in local establishments by cutting into patterns and punching. The waste from the mines and scrap from the cutting houses is ground in local mills or shipped to mills outside of the State.

ORIGIN.

Mica of commercial size in North Carolina occurs only in pegmatite. It is uncertain whether this rock should be classed with dikes or veins. It is probable that some bodies are true dikes, whereas others may be vein formations. A large number fall into an intermediate class, of which it is not likely that a reference to either origin can ever be made. There seems to be no reason against accepting an intrusive origin for the majority of those pegmatites which have a typical granitic texture and in which none of the constituent minerals are separated out in sheetlike masses parallel to the walls, especially those that are more persistent in extent in regions where granite intrusions are of large size or plentiful. On the other hand, it does not seem reasonable to consider certain forms of pegmatite, occurring in the region studied, as true igneous injections. In this statement are included such pegmatites as are illustrated in figs. 16 and 17 and probably also in fig. 15. In each of these masses banding is evident.

Fig. 16 represents a vein cutting a mass of coarse granite or pegmatite in a region of granite intrusions. The vein is composed of the same minerals, coarsely crystallized, as in pegmatite, and is itself pegmatite. It is evident that there have been several stages in its formation. Apparently the mica-feldspar bands along the walls were

first formed, followed by the quartz, and then in the middle by the streak composed chiefly of feldspar. It is possible that the feldspar formed in a fissure in a once solid mass of quartz; though it probably occupies the portion of the original fissure that was never quite closed by the quartz. Fig. 17 represents an occurrence that is uncommon, though it possesses certain features bearing on the origin of pegmatite. The history shown by this deposit may be briefly described as follows: After movements associated with mountain building had ceased—that is, in Carboniferous time or later—the granite dike was forced into a fissure or line of weakness cutting across the foliation of the country rock. Cooling was fairly rapid, and the texture was consequently rather fine. This was followed by the deposition of pegmatite from solutions passing along each side of the dike. A source for such solutions could be found in the final stages of activity of the magma from which the granite was formed.

These two illustrations are given to show that the formation of certain pegmatites is much more readily explained by referring it to aqueous agencies than to intrusion as an igneous body. With the probability thus established of an aqueous origin for certain pegmatites and an intrusive origin for others, we are confronted by a large number the nature of whose origin is difficult to decide. Among these are many pegmatites like that represented in fig. 15, in which there is a banding consisting of a streak of feldspar with a little quartz mixed through it lying on each side of a quartz band. Locally there are several quartz bands in the pegmatite. It is the opinion of the writer that such pegmatites are in part, if not wholly, of vein origin. The feldspar component, in many places containing more or less quartz mixed through it, may have been intruded as a magma and the whole modified by the secondary introduction of quartz by solutions. It seems more likely, however, that if a part is to be considered the result of aqueous agencies the whole pegmatite should be so considered. A strong argument in favor of the deposition of these quartz bands from solution is afforded by the peculiar banding, apparently not due to strain, observed in the quartz streak at the Lyle Cut mine. (See p. 412.)

The blending between the conditions of fusion and solution conceived to exist under heat and pressure, such as prevail in deeply buried granite magmas where water is present in considerable quantity, has been well set forth by Van Hise,[a] Crosby and Fuller,[b] and Williams.[c] As stated by Van Hise, given the two conditions, a magma and a solution with no sharp line of demarcation between them, we may expect to have injections of dikes and aqueous cementation, which grade into each other and between which no sharp distinction

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[a] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904.

[b] Crosby, W. O., and Fuller, M. L., Origin of pegmatite: Am. Geologist, vol. 19, 1897.

[c] Williams, G. H., General relations of the granitic rocks in the Middle Atlantic Piedmont Plateau: Fifteenth Ann. Rept. U. S. Geol. Survey, 1895.

can be drawn. Van Hise further cites the occurrence of pegmatite in metamorphic rocks in the Marquette district of the Lake Superior region, where no parent granite mass was found, and concludes that the pegmatite was formed by the metamorphism of the rocks through mechanical action aided by aqueous agencies.

It is thought that these views are applicable to the pegmatites of North Carolina. Some are so clearly associated with large granite intrusions and are so like granite in their behavior toward the country rock that the theory of intrusive origin seems particularly appropriate. Others also in regions of granite masses exhibit structures so similar to those generally attributed to vein formations that they must be considered of aqueous origin. Still others show structures common to both igneous masses and vein formations and must be placed in the intermediate stage set forth by Van Hise. There are pegmatites within the areas of the Carolina and Roan gneisses which are so far removed from any known granite masses that it seems probable that they were produced during the metamorphism of the inclosing rocks, like those of the Marquette district. This theory is more plausible when the great extent of the regional metamorphism of the Carolina and Roan gneiss formations and the large number of small pegmatite streaks cutting them at all angles are taken into consideration.

The occurrence of drusy cavities, comb structure, and regular banding, such as is common in many fissure-vein deposits, is observed in few places, if anywhere, in the mica-bearing pegmatites of North Carolina. This is not to be wondered at when the conditions of the formation of pegmatite are considered. The materials are probably derived from deep-seated magmatic or metamorphic sources, and the pegmatite was formed at great depth under conditions of heat and pressure. If the material was itself a magma, the resulting form would be a dike, in which formation cavities are never looked for, except near the surface. If the material was a solution, either of magmatic or metamorphic origin, a vein would be produced. That veins do not necessarily have banded structure nor drusy cavities is plainly shown by many of the auriferous quartz veins of the southern Appalachians, in which genuine banding or crustification is rare and the majority show no trace of either. These veins are the mere stumps of a once extensive vein system that has been eroded away along with several thousand feet of the formations in which they occurred. According to Graton,[a] these veins were formed by heated solutions forced, under great pressure, into what in many cases may have been the merest fractures and depositing their loads. The force of crystallization may also have aided in expanding the openings, but the principal force is supposed to be due to the pressure exerted by the weight of overlying formations on these solutions at a lower depth than that at which the vein

[a] Graton, L. C., Gold and tin deposits of the southern Appalachians: Bull. U. S. Geol. Survey No. 293, 1906, p. 60.

was formed. It is thought that pegmatite veins may have formed in very much the same way as these auriferous quartz veins. Under similar conditions heated solutions, carrying the constituents of pegmatite instead of those of gold-bearing quartz veins, would form regular veins of pegmatite. Any irregularities in the composition of the solutions would produce the banding already described as of common occurrence in pegmatites.

It is difficult to conceive of the formation by injection, as an ordinary magma, of pegmatite in streaks or bands a fraction of an inch thick in gneissic rocks, in many places having no visible connection with other pegmatite bodies. On the other hand, it is easy to conceive of a solution being forced through the smallest fractures or working its way between the mineral particles and depositing its load. The latter process would not require such high temperatures, either in the solution or country rock, as would be required for the injection of a magma in order that it might not be cooled so quickly as to prevent coarse crystallization. The possibility of the formation of these smaller pegmatites by the injection of a highly fluid aqueo-igneous magma is not denied, especially if the magma approaches closely the conditions of a solution. It is thought, however, that aqueous processes afford a simpler and, therefore, more reasonable explanation.

Pegmatization of rock masses, so common in the Carolina gneiss, especially in the Piedmont Plateau region, has probably resulted from one or both of two causes—namely, either recrystallization due to aqueous agencies or the addition of more material from solutions passing through the formations. In the first process occluded water in the rock, aided by the heat generated during regional metamorphism, may have caused recrystallization and consequent pegmatitic texture. In the second process it is probable that pegmatization has resulted from solutions which were forced through the rock along cracks, seams, or bedding planes and there deposited their load. Where pegmatization is characterized by much feldspar, it is probable that these solutions were of magmatic origin, and one generally does not have to look far to find a granite intrusion in the neighborhood.

It is thought that pegmatites occurring in irregular masses, streaks, lenses, augen, or balls, and having no visible connection with other pegmatite bodies, are generally the result of aqueous action. A solution could be readily forced through fractures or seams along the bedding planes and deposit its load only in the more favorable places. If such bodies were formed by intrusions, it would be necessary to consider that the walls of the dike had been forced together, closing the passage through which the magma had passed. Though the possibility of such conditions is not denied, a simpler method of formation, as deposition from solution, is considered more probable. In augen and ball-shaped bodies of pegmatite without visible connection with

other pegmatite masses, room for the segregation was probably produced by the expansive force of the growing feldspar crystals, which have crowded the gneiss or schist out on each side.

SUMMARY OF CONCLUSIONS.

It is uncertain whether pegmatites should be called intrusions or vein formations. It is probable that some are dikes and others are veins. Those with a typical coarse granitic texture are probably of intrusive origin; those with a banded structure are probably the result of aqueous deposition. In view of certain examples, already illustrated by figures, these statements become more acceptable. Van Hise's conception of the condition of pegmatite material before the pegmatite was formed seems particularly applicable in this region; that is, given a magma and a solution with no sharp line of demarcation between them there may be intrusions and aqueous cementation also grading into each other. Graton's interpretation of the formation of the auriferous quartz veins of the southern Appalachians also seems particularly appropriate in accounting for pegmatite veins; that is, the solutions were forced into fractures or fissures under great pressure and by the aid of the expansion produced by the crystallization of the minerals being deposited, spread the walls apart sufficiently to allow the formation of the veins. The occurrence of much pegmatite in small streaks through the rock formations is probably caused either by recrystallization through the combined action of water and heat or by solutions being forced through fractures or seams and depositing their loads, or by both. It might also be possible for such pegmatization to be produced by the injection of an extremely fluid aqueo-igneous magma into and through the formations. Disconnected bodies of pegmatite are also more readily explained by deposition from solution than by intrusion as dikes.

The question of the origin of pegmatites is chiefly of scientific interest rather than of commercial importance; for good deposits of mica are found in rocks of both dike and vein types. The quality of the mica from one type is in general no better than that from the other. It is probable, however, that those pegmatites which are typically of intrusive origin will be found to hold out longer than those with veinlike structure. Although the available evidence is insufficient to prove this definitely, there are certain dikelike masses that have been followed long distances or to considerable depth and found to carry paying mica to the limits worked. On the other hand, many veinlike deposits have been opened and large quantities of mica recovered from certain portions, and then the "vein" has abruptly become poorer or pinched out. Of course there are veinlike deposits which have been worked through considerable distances; though probably none have held out so persistently as the bodies of intrusive origin.

MICA IN THE HARTVILLE UPLIFT, WYOMING.

By Sydney H. Ball.

INTRODUCTION.

During the field season of 1906 the writer examined the mica prospects of the Hartville uplift, situated in the rugged hills among which Haystack Peak is the most prominent. (See fig. 5, p. 192.) They are located upon pegmatite dikes cutting pre-Cambrian schists. These schists, which form the uppermost member of the older sedimentary series,[a] are closely folded and intensely metamorphosed near the granite of the Haystack Hills. The mica-bearing area lies to the east of Whalen Canyon and to the west of Cottonwood Canyon, and its north and south boundaries are respectively McCanns Pass and an east-west line passing through Haystack Peak. The possibly productive area includes all or parts of secs. 25, 26, 27, 34, 35, and 36, T. 28 N., R. 65 W., and secs. 1, 2, and 3, T. 27 N., R. 65 W.

The first mica claim, named the Savage, was located by Joseph L. Stein in 1881. Other prospects were soon taken up, and work has been done on some of them up to the present day, but with an unimportant exception no muscovite has been shipped. At present four prospects appear promising.

Muscovite in commercial quantities is confined to dikes of pegmatite, which cut the schists. These dikes were intruded after the schist became fissile, and in consequence trend in the main parallel to the schistosity, although in places they cut across it. The dikes vary from thin stringers to irregular intrusive masses one-fourth mile wide. In many places their width is constant, but here and there it changes markedly within a short distance. The pegmatite is composed of the following minerals, named in the order of their abundance: Feldspar (orthoclase, microcline, and albite), quartz, muscovite (white mica), black tourmaline, beryl, brown garnet, and biotite. It is in general coarsely granular, the mineral bodies varying in diameter from one-fourth inch or less to 2 feet or more. Such extreme variations are rarely seen in a single dike, although important changes in the sizes of grains take place within comparatively short distances. The distribution of the minerals in the pegmatite is, as a rule, fairly even, although

[a] For the succession of the pre-Cambrian rocks of the Hartville uplift see pp. 193–194 of this volume.

locally muscovite in particular occurs in bunches of books. Liquids and gases originating from the pegmatitic magma have considerably metamorphosed bands of schist on either side of the pegmatite dikes.

DESCRIPTION OF PROSPECTS.

The principal mica prospects of the Hartville uplift are the Crystal Palace, the Savage, the New York, and the Minnie.

The Crystal Palace claim, owned by Lauck & Stein, is situated on the south side of a steep valley in the center of the NE. ¼ sec. 34, T. 28 N., R. 65 W. An open cut 60 feet long has been made on a pegmatite dike 6 feet wide at its floor and 15 to 18 feet wide at its top. At the southwest end of the cut the pegmatite is covered by talus, but it is exposed for a long distance along its strike, which is N. 60° E. It is a coarsely crystalline aggregate of feldspar, white quartz, muscovite, tourmaline, brown garnet, and a little beryl. The black tourmaline is not prominent and is largely confined to the edges. Quartz was the last mineral of the pegmatite to solidify and a portion of it was still held in solution by the magmatic waters after the pegmatite had consolidated, since it also occurs in indistinct veins which cut the pegmatite. The distribution of the muscovite is bunchy and in consequence an estimation of the amount of muscovite in the walls of the open cut is difficult, although it probably forms from 10 to 15 per cent of the pegmatite. The muscovite tends to form hexagonal plates, some of which are 2 feet across and 3 or 4 inches thick. It is a good-grade "water" mica, although rulings are common and in some of it plates of feldspar and quartz lie between the mica leaves. To the northeast across the gulch the pegmatite contains a greater proportion of tourmaline and beryl, and though muscovite is equally abundant, the plates are much smaller. At present there are 2 or 3 tons of mica on the dump. Some of this is high-grade material which could be used for sheets.

The Savage claim, also the property of Lauck & Stein, is situated near the center of the S. ½ sec. 26, T. 28 N., R. 65 W. An open cut is here located on a pegmatite dike 10 feet wide, which courses N. 65° E. About 200 feet farther southwest the dike either pinches out or plunges beneath the surface, and to the northeast it becomes narrower and the muscovite plates become smaller. The composition of this pegmatite is similar to that at the Crystal Palace claim, although bluish-green beryl is more abundant. In many places thin distorted crystals of tourmaline lie between the muscovite leaves. Muscovite in plates, some of them 12 inches in diameter, forms 10 to 15 per cent of the pegmatite. From this prospect sheets of mica 11 by 13 inches and free from flaws have been obtained.

The New York claim is situated in the northeast corner of sec. 35, T. 28 N., R. 65 W., and is owned by Mr. Frederick. At the open cut the pegmatite dike is from 6 to 10 feet wide; it narrows to 5 feet 350

feet to the west, but widens to 50 feet 500 feet still farther west. The pegmatite varies considerably in the size of its constituent minerals. Muscovite occurs in plates up to 20 inches in diameter, although the largest plates are commonly ruled. The larger flawless plates are from 6 to 8 inches in diameter.

The Minnie claim, situated southwest of the center of sec. 35, T. 28 N., R. 65 W., is also owned by Mr. Frederick. The largest sheets obtainable on this claim are 8 inches in diameter.

Plates of mica 10 inches across were seen in a pegmatite dike in the north center of sec. 35, T. 28 N., R. 65 W. This dike is characterized by beryl crystals 4 feet long. Plates of muscovite 8 inches in diameter occur in a pegmatite dike in the center of the SE. ¼ sec. 35.

COMMERCIAL CONDITIONS.

The pegmatite dikes in which large sheets of mica occur vary in width from 5 to 18 feet and carry from 10 to 15 per cent of muscovite. It is probable that at least in the four prospects described, muscovite is present in commercial quantities. There is a marked variation in the width of the dikes, along both the strike and the dip, and the size of the mica plates is by no means uniform in different portions of the same dike. The mica is clear and of good quality, although varying amounts of it are ruled and feldspar, quartz, and tourmaline occur between the leaves of some of the books.

Mica mines situated in the Western States are operated at a considerable disadvantage on account of the high freight rates to the eastern market. A mine in the Black Hills, South Dakota, however, whose transportation facilities are comparable in a general way to those of the prospects at the Hartville uplift, has shipped mica to Illinois, apparently at a profit. High freight rates also prohibit the utilization of feldspar and quartz, common by-products of mica mines, in the manufacture of pottery. These Wyoming prospects would furnish a considerable percentage of sheet mica for the glazing trade. Although large mica plates are in less demand than formerly for stove doors, since smaller sheets are now used in paneled doors, the introduction of mica lamp chimneys has perhaps offset this decrease in the demand. Smaller plates could be used in making composite sheets of mica called mica board or micanite, and the waste mica could be shipped for grinding. The mica of these prospects would probably bring from 35 to 50 cents per pound. The Crystal Palace and Savage claims can readily be reached by road, and the mica can be hauled to Ironton, Wyo., on the Chicago, Burlington and Quincy Railroad, for $1.25 per ton. The cost of transportation from the New York and Minnie claims would be somewhat greater. It is probable that under careful management mica of excellent quality could be produced in the Haystack hills at a small profit.

GRAPHITE IN THE HAYSTACK HILLS, LARAMIE COUNTY, WYO.

By Sydney H. Ball.

GEOGRAPHY AND GEOLOGY.

In the summer of 1906 the writer examined the graphite properties of Laramie County, Wyo., situated in the rugged hills around Haystack Peak, which lies to the east of Whalen Canyon and to the west of Cottonwood Canyon. (See fig. 5, p. 192.) The most promising graphite-bearing area includes secs. 14, 15, 22, 24, 25, 26, 27, 34, 35, and 36, T. 28 N., R. 65 W., and sec. 1, T. 27 N., R. 65 W., although graphitic schist occurs in the vicinity of Rawhide Buttes.

The first prospecting for graphite in these hills was done by Messrs. Lauck & Stein, who in 1881 located the so-called Sentinel claim, south of Hamilton Pass. Since that time little interest has been shown in the graphite and no shipments have been made.

The graphite occurs in the immediate vicinity of granite and pegmatite as a constituent of the pre-Cambrian muscovite schist of sedimentary origin.[a] Of the larger intrusive granite masses of the Haystack Hills one alone—that to the north of McCanns Pass—has metamorphosed this schist to a graphitic phase. The schist varies from a silvery muscovite variety containing but little graphite to a grayish-black sectile rock. Such gradations occur, as a rule, across the strike, although to a less degree along it. On microscopic examination the schist unaffected by the granitic and pegmatitic intrusions is seen to contain carbonaceous matter, and the graphite is this material altered by the intense heat and other agents attendant on the intrusions.

OCCURRENCES.

The most extensive graphite showing is on the north side of McCanns Pass, 2,000 feet east of the summit, in sec. 26, T. 28 N., R. 65 W. About 300 feet of schist, which, although it is intruded by a large pegmatite dike, is of the normal muscovitic variety, lies between the granite and the graphitic band, striking N. 55° E. and

[a] For an account of the pre-Cambrian succession of the Hartville uplift, see pp. 193-194 of this volume.

dipping 70° NW. The graphitic schist is exposed in two outcrops 2 feet apart, each 4 feet wide measured across the bedding, indicating, if each is in place, a thickness of 10 feet. This rock varies in composition across the strike from a coarsely schistose muscovite-graphite phase to a graphite schist of grayish-black color. Beyond this point the rocks are covered by alluvium for 1,000 feet to a second exposure along the same strike, showing an 8-foot band of rather high-grade semischistose graphitic rock, portions of which are considerably iron stained. From this exposure the band can be traced westward 1,000 feet on the north side of McCanns Pass, at first by abundant and then by fewer outcrops and many residual masses. The graphitic band gradually approaches the granite and is finally cut out by it. At the contact of the schist with the granite a tunnel exposes 10 feet of graphitic schist.

A band of graphitic schist 2 feet wide occurs on the south side of the gap in the center of the NE. ¼ sec. 1, T. 27 N., R. 65 W. This band has a strike of N. 70° E. and a vertical dip. It can be traced along the strike for several hundred feet to the alluvium on either side. Large bodies of pegmatite lie within 35 feet north and south of the graphite. The grade of the graphite is lowered by the presence of contorted veins of quartz which lie along the foliation planes of the schist. High-grade graphitic schist has also been thrown from a prospect pit in the center of the W. ½ sec. 14, T. 28 N., R. 65 W. It occurs also in the north-central part of the NE. ¼ sec. 26, in the northeast corner of sec. 27, in the center of the SW. ¼ SE. ¼ sec. 23, and in the northwest corner of sec. 26, T. 27 N., R. 65 W. In sec. 26 some tourmaline is associated with the graphitic schist.

COMMERCIAL CONDITIONS.

As seen under the microscope the graphitic schists contain much finely disseminated graphite associated with quartz, tourmaline, and a little biotite, muscovite, and feldspar. The richest specimens appear to contain up to 16 per cent of carbonaceous matter, all of which is either in ragged particles or hexagonal plates and has the microscopic habit of graphite. One of the richer specimens analyzed by E. C. Sullivan afforded by the Wittstein method 13 per cent total carbonaceous matter and 5 per cent graphite. Doctor Sullivan states that this method may not determine all of the graphite and that the other carbonaceous matter present is practically nonvolatile. On chemical and microscopic grounds, then, it is probable that all the carbonaceous matter present may be commercially considered graphite. It is estimated that the 10-foot bed in McCanns Pass would run from 6 to 8 per cent graphite. The graphite individuals are very small, having an average diameter in various thin sections

of 0.04 to 0.15 mm. To separate such finely divided graphite from the minerals associated with it would require very fine grinding and, although the percentage of mica in the schist is small, the expense of a clean separation of the graphite and mica to form a high-grade product would be prohibitive. The graphite is of the variety known in the trade as amorphous graphite and is suitable only for paint, other coloring matter, and foundry facings.

Haulage from the graphite bed to the Chicago, Burlington and Quincy Railroad at Ironton, Wyo., costs, approximately, \$1.25 to \$1.50 per ton.

Under the conditions which control the American graphite trade at present, it is exceedingly improbable that these deposits can be worked at a profit. At some future time, however, they may be of commercial importance. This is more particularly likely to be true of the bed in McCanns Pass, which is 8 to 10 feet wide.

SURVEY PUBLICATIONS ON MICA, GRAPHITE, ETC.

The following list includes a number of papers, published by the United States Geological Survey or by members of its staff, dealing with various nonmetallic mineral products:

BAIN, H. F. Fluorspar deposits of southern Illinois. In Bulletin No. 225, pp. 505–511. 1904.

BREWER, W. M. Occurrences of graphite in the South. In Seventeenth Ann. Rept., pt. 3, pp. 1008–1010. 1896.

EMMONS, S. F. Fluorspar deposits of southern Illinois. In Trans. Am. Inst. Min. Eng., vol. 21, pp. 31–53. 1893.

FULLER, M. L. The occurrence and uses of mica. In Stone, vol. 19, pp. 530–532. 1899.

HAYES, C. W., and ECKEL, E. C. Occurrence and development of ocher deposits in the Cartersville district, Georgia. In Bulletin No. 213, pp. 427–432. 1903.

HOLMES, J. A. Mica deposits in the United States. In Twentieth Ann. Rept., pt. 6, pp. 691–707. 1899.

KEITH, A. Talc deposits of North Carolina. In Bulletin No. 213, pp. 433–438. 1903.

KEMP, J. F. Notes on the occurrence of asbestos in Lamoille and Orleans counties, Vt. In Mineral Resources U. S. for 1900, pp. 862–866. 1901.

——— Graphite in the eastern Adirondacks. In Bulletin No. 225, pp. 512–514. 1904.

PHILLIPS, W. B. Mica mining in North Carolina. In Mineral Resources U. S. for 1887, pp. 661–671. 1888.

SMITH, G. O. Graphite in Maine. In Bulletin No. 285, pp. 480–483. 1906.

STOSE, G. W. Barite in southern Pennsylvania. In Bulletin No. 225, pp. 515–517. 1904.

ULRICH, E. O., and SMITH, W. S. T. Lead, zinc, and fluorspar deposits of eastern Kentucky. In Bulletin No. 213, pp. 205–213. 1903.

MINERAL PAINTS.

SOUTHERN RED HEMATITE AS AN INGREDIENT OF METALLIC PAINT.

By Ernest F. Burchard.

INTRODUCTION.

At certain localities in northwestern Georgia and southeastern Tennessee the Clinton oolitic hematite occurs in beds too thin to be profitably mined as iron ore under present conditions. Much of this red ore is of the "soft" variety and contains an unusually high percentage of ferric oxide, with but little silica and alumina and practically no lime. Its chemical composition renders it an ideal red-paint material and, owing to its physical condition, it is easily crushed and ground. With the rapid increase of building in the South, together with the manufacture of railroad cars and structural iron, has come a demand for metallic paint that has given these beds of ore an unexpected importance.

The reasons why this ore can be profitably mined for paint material and not for iron making are briefly these. In order to bring the cost of production within the limits of market prices of smelting ores, mining must be conducted on a scale involving the use of power, cables, and general mine equipment, and usually a railroad spur a mile or more in length would have to be built. The total amount of ore in sight indicates that the beds would be exhausted too soon to warrant this outlay. Furthermore, the nature of the deposits is likely to be such that a larger quantity of shale than ore would have to be removed either to win the ore or to provide the head room necessary for regular mine work, thereby rendering it doubtful whether the ore could profitably be worked for iron, even if the quantity in sight were assuredly greater. When the right kind of ore occurs under these conditions, it is sufficiently valuable to paint manufacturers to bear the cost of

mining by hand and of haulage by wagon to the nearest railroad. Ordinary grades of iron ore, such as are smelted in the district, are not suitable for paint manufacture, and therefore they can not compete with the more expensive material here considered, although a small amount of high-grade ore that would otherwise be smelted is sold by the iron producers to paint makers on account of the good price it commands.

Most of this ore that is used for paint is ground by mills at Chattanooga, but a part of it goes to Birmingham. The paints made are the reds and dark browns, and a considerable quantity of the ground oxide is sold for coloring sand-lime bricks and mortars for pressed-brick work.

Geologic maps of the Chattanooga and Ringgold quadrangles show the distribution of the Rockwood ore-bearing formation in this region. These maps have been published in folios Nos. 6 and 2, respectively, of the Geologic Atlas of the United States, issued by the United States Geological Survey, and are available in many public libraries and in the offices of many mining companies. To persons familiar with the region the beds containing ores of value for iron making are fairly well known, but much of the territory intervening between the iron-mining centers has never been prospected with reference to the value of the ores for paint manufacture.

GEOLOGIC RELATIONS AND DEVELOPMENT.

GEORGIA.

Wildwood.—Along the west base of Lookout Mountain extends the anticlinal Lookout Valley. On both sides of this valley is exposed the Rockwood formation, with its strata dipping away from the axis. In Lookout Valley this formation consists of about 600 feet of calcareous shale, with some beds of blue limestone and fossiliferous hematite. Above the Rockwood and separated from it by a few feet of black Chattanooga shale lies the Fort Payne chert; below the Rockwood is the Chickamauga limestone. The Fort Payne chert has offered greater resistance to erosion than the adjacent rocks, and its base forms the crest of a ridge on either side of Lookout Valley, with the Rockwood shale on the inner slopes of the ridges. The Alabama Great Southern main line traverses this valley at distances of a quarter to half a mile from the eastern ridge.

The eastern ridge, particularly at New England, furnished soft iron ore to Chattanooga furnaces for many years, but now the ore obtainable by trenching or stripping has become exhausted and mining activities are for the most part temporarily suspended. At Wildwood, however, where the soft ore has been found suitable for paint manufacture, there is still some ore available for that purpose, part of

which was awaiting shipment in May, 1906. The rock lies nearly flat here and shows the following section:

Section of paint-ore bed at Wildwood, Ga.

	Inches.
Shale.	
Ore	8
Shale	$\frac{3}{4}$
Ore	10
Shale	$\frac{1}{2}$
Ore	9
Shale.	

Estelle.—East of Lookout Mountain the Rockwood formation becomes thicker and contains less limestone, sandy shale and beds of sandstone being developed. At Estelle is exposed a good railroad section of the formation, nearly continuous from the Chickamauga limestone below to the Chattanooga shale above, and from this section, in which the rocks dip at angles of 5° to 9°, the thickness is computed to be 960 feet. The ore seams are just below the middle of the formation. Two ore beds about 25 feet apart, outcropping on the northwest side of the Pigeon Mountain syncline, are worked extensively at Estelle for iron ore to supply the Southern Steel Company's furnace at Chattanooga. The beds at this place dip 5° to 14° S. 50° E., and are to a large extent under a shallow cover, especially the upper bed. The lower bed is so thoroughly leached and so pure in places that the ore from certain openings at the mine is sold for paint manufacture rather than for smelting. On the west side of the hollow through which the Chattanooga Southern Railway passes are two openings, driven on the strike of the beds for 200 feet or more entirely in soft ore. The cover over the beds here is only 16 to 20 feet thick. Where covered by enough shale to include the higher ore bed the ore of the lower bed becomes hard. The following section shows the character of the lower ore bed at a distance of 200 feet from the mouth of one of these openings.

Section in soft-ore opening at Estelle, Ga.

	Inches.
Shale.	
Soft ore	1
Hard shale or "jack rock"	5
Soft ore	15
Shale	2
Soft ore	8
Shale.	

The composition of some of the ore from this place is shown by the following analysis:

Analysis of soft ore from lower seam, Estelle, Ga.

[Authority, Southern Steel Company, Chattanooga.]

Ferric oxide	72.86
Insoluble	21.00
Phosphorus	.40
Manganese	.30

TENNESSEE.

The red-paint ore produced in Tennessee is obtained mainly from White Oak Mountain and a smaller ridge lying to the east of it. The mines are all within 4 miles of Ooltewah, a station on the Southern Railway 15 miles east of Chattanooga.

White Oak Mountain is developed on the west limb of a narrow syncline that trends N. 15° E. The Rockwood formation, here consisting largely of hard brown sandstone, forms the ridge of White Oak Mountain; also the lower ridge, about a mile farther east, on the east limb of the syncline. The upper portion of the formation appears to contain the ore beds and their inclosing shales. Nearly twenty years ago soft ore was obtained in large quantities from surface workings near the cuts of the Southern Railway through Julian Gap and McDaniel Gap, and from the strip of White Oak Mountain, 2 miles long, between these gaps, considerable soft ore has been removed in past years. At present underground mining is in progress here. On the Tallen, Parker, and Craven properties a bed 14 to 18 inches thick, containing in places a shale streak, is worked by slopes and short drifts driven along the strike of the bed, with rooms turned up and down the dip. The main openings—perhaps 30 inches in height—are high enough only to admit a shallow car, and the miners must crawl in on hands and knees and work in a sitting posture. The roof over the main entry is in most places supported by posts, but a few of the rooms are timbered. None of the workings have been carried underground more than 75 feet. The beds dip 22°–25° S. 65° E., but there are many minor crumplings in the strata that change the dip considerably and make mining more difficult. The ore is so firm that it has to be blasted, yet it is thoroughly leached. The material is very fossiliferous and apparently contains only a moderate amount of silica for a well-leached ore. The partial analysis of an Ooltewah paint ore from this locality is as follows:[a]

Partial analysis of Ooltewah paint ore.

Silica (SiO_2)	11.90
Iron oxide (Fe_2O_3)	83.14

The mines on these properties are being worked by lessees, who pay 25 cents a ton royalty on the ore taken. The ore is hauled by team 1½ miles to Wells switch at a cost of about 50 cents a ton, or wagonload, and it brings $2.85 on the cars. The freight, 30 cents a ton to Chattanooga, is paid by the purchasers. Each miner gets out about 1 ton of ore per day, and wages run from $1 to $1.50 per day. It is plain that the cost of the ore is such that while red ore for smelting sells at about $1 per ton these ores are not available for making iron.

[a] Bowron, W. M., The Iron Ores of the Chattanooga District, Chattanooga Chamber of Commerce, November, 1903, p. 4.

North of Wells switch, or Julian Gap, the ore is being worked in a small drift with upshoots. The ore is a deep red, firm material with flattened grains mingled with fragments of crinoid stems, all of pure hematite. The bed varies in thickness, thinning from 14 down to 5 inches owing to a squeeze from the overlying shale. The average thickness is about 10 inches and it seems possible to mine a bed as thin as this where there is but a short wagon haul to the switch. A second seam of ore, 6 to 7 inches thick, occurs 3 feet below, but is not worked.

In the valley east of the Craven property considerable ore in lumps and pebbles of the size of cobblestones has been strewn by erosion down the stream gullies and over the fields. This pebbly ore is being gathered and shipped to the paint manufacturers.

The total shipments from Wells switch amount to about 50 tons per month.

In the ridge on the east limb of the White Oak Mountain syncline, north of Hinch's switch, the red ore occurs apparently in two beds, but examination discloses the fact that a single bed of ore has been repeated by a close, overturned fold. Locally the same bed is displaced and repeated by faulting, and 1 mile south of Hinch's switch the entire Rockwood formation on the east limb of the anticline is engulfed in a fault. The ore, where it is mined north of the railroad in the east ridge, averages 12 inches in thickness, although it reaches 16 inches in places. Within the seam are a few partings of shale, locally developed. Blocks of the ore show slickensides perpendicular to the bedding. From Hinch's switch northward for 4 miles soft ore has been stripped for furnace use. At present underground drifts and slopes about 1 mile north of the railroad, owned by the Chattanooga Paint Company, are in operation. About 35 tons of paint ore a week are shipped from this point. The approximate composition of the ore is as follows:[a]

Analysis of ore from Chamberlain tract, north of Hinch's switch.

Silica (SiO_2)	16.45
Ferric oxide (Fe_2O_3)	80.00
Phosphorus (P)	.28
Water (H_2O)	1.81

[a] Bowron, W. M., op. cit., p. 4.

THE MINERAL-PAINT ORES OF LEHIGH GAP, PENNSYLVANIA.

By Edwin C. Eckel.

During the summer of 1906, while the writer was in southeastern Pennsylvania examining the brown iron-ore deposits of that region, advantage was taken of a favorable opportunity to examine the well-known "paint-ore" mines and works near Lehigh Gap, in Carbon County, Pa.

Geology of the deposits.—A typical section in this district would be about as follows, from above downward:

Section containing paint ore.

	Feet.
Black slates (Marcellus).	
Clayey limestone ("Upper Helderberg")	0–6
Clay	0–1
Paint ore	0–6
Clay	2–20
Sandstone (Oriskany).	

The paint ore is an impure iron carbonate containing considerable clayey matter and some lime carbonate. Near the surface it weathers into brown oxide of iron. The "bed" of paint ore is not continuous, but thickens or thins, and in places disappears entirely. As to its continuity in depth no definite data are available, but at several mines the ore is said to thin markedly in depth, while the limestone bed thickens. These conditions can perhaps be interpreted best by assuming that the "paint-ore" deposit is the result of a replacement of the "Upper Helderberg" limestone.

Other occurrences of iron ore in the vicinity lead to the same conclusion. About one-half mile west of Millport, for example, the Oriskany sandstone shows an interesting exposure. Here a white residual clay is being worked in or below the Oriskany sandstone, which itself has been extensively quarried for sand. The point of interest is that the upper beds of the sandstone show replacement by brown ore along bedding and joint planes, while in places the replacement has affected the mass of the rock. Some specimens show a mass of brown ore inclosing scattered grains of sand. Evidently the

cementing material of the sandstone is less resistant than the grains themselves; but at times even the sand grains show replacement by brown ore. The result, on a very small scale, is the formation of ores like those of the Rich Patch, Lowmoor, and Longdale mines of Virginia.

Character of the paint ore.—The typical paint ore is light blue in color and rather distinctly laminated. Except for weight it might readily be mistaken for a sandy shale. Occasionally fossils are present in the ore, in which case it looks still less like an iron ore. Grains and nodules of iron pyrite are scatterd through the ore, but not to any considerable extent. The larger nodules of pyrite are picked out before the ore is sent to the kiln, and some sulphur is roasted off, but a sufficient number of small grains remain to give the paint a sulphur content of one-half to 1 per cent.

Analysis of crude paint ore, Lehigh Gap district, Pennsylvania.

Silica (SiO_2)	16.21
Alumina (Al_2O_3)	5.49
Iron oxide (FeO)	44.50
Manganese oxide (MnO)	1.19
Lime (CaO)	3.51
Magnesia (MgO)	1.08
Sulphur (S)	.67
Phosphorus (P)	.02
Carbon dioxide and organic matter	24.35
Water	

The analysis given above was made by Mr. A. S. McCreath.[a] The sample analyzed is evidently far richer in iron than the average material used in the manufacture of paint, as can be seen in comparing the above analysis with the analyses of finished paint given later.

Methods of manufacture.—Two firms are now operating in the district. Prince's Manufacturing Company is operating two kilns (one west of Millport, the other at Bowman's), and three mills, all at Bowman's. The Prince Metallic Paint Works operates kilns and a mill about half a mile east of Lehigh Gap.

The kilns used in the district are circular internally, with an interior section about 5 feet in diameter and about 16 feet in height. The fuel used is wood, burned in two furnaces, the heat being conveyed to the charge by a checkerwork of brick.

The ore is charged at the top of the kiln at the rate of 8 to 10 long tons a day. As the kiln holds about 16 tons, the ore is roasted for about two days. One cord of wood will roast 8 to 10 tons of ore. During the roasting the ore loses from 10 to 20 per cent in weight, and the lumps assume a brownish-yellow color on the outside. When broken open and pulverized, the powder is a deep brownish red.

[a] Ann. Rept. Pennsylvania Geol. Survey for 1886, pt. 1, p. 1404.

The roasted ore is crushed to about quarter-inch size in a Mosser pot crusher and then pulverized by millstones. The latter are of several types. At a plant at Bowman's five of the six stones in use were French buhrs; the other was a vertical rock-emery mill. At the Lehigh Gap plant all of the seven mills were rock-emery. Four of them were horizontal under runner stones; the other three were vertical. It is generally assumed that six sets of stones will handle the product from one kiln.

Character of the product.—The composition of the metallic paint from this district is fairly indicated by the following analyses:

Analyses of finished metallic paint, Lehigh Gap district, Pennsylvania.

	1.	2.	3.	4.
Silica (SiO_2)	37.20	37.20	35.30	37.79
Alumina (Al_2O_3)	9.60	9.40	10.70	10.61
Iron oxide (Fe_2O_3)	43.30	42.70	43.30	41.28
Manganese oxide (MnO)	.35	1.40	1.83	1.27
Lime (CaO)	.10	1.70	2.00	3.00
Magnesia (MgO)	3.35	1.70	1.91	2.03
Sulphur trioxide (SO_3)	2.38	1.88	1.95	1.94
Phosphorus pentoxide (P_2O_5)	.17	.14	.15	.14
Carbon dioxide and organic matter (CO_2)	2.40	2.60	1.50	2.68
Water	.60	.60	.90	......
Metallic iron (Fe)	30.30	29.90	30.30	28.90
Sulphur (S)	.95	.75	.78	.77

Analyses 1, 2, 3 furnished by Mr. Thompson, president Prince Metallic Paint Company; analysis 4 quoted from Ann. Rept. Pennsylvania Geol. Survey for 1886.

The paint made in this district is a browner red than that made from the oolitic red hematites at Franklin, N. Y., and Chattanooga, Tenn. It is used mostly for car and other structural work, very little being used as mortar color.

Until quite recently the standard package for this paint was a 300-pound barrel, but now the larger consumers (car shops, etc.) prefer a 500-pound barrel. A portion of the product is packed in 100-pound kegs.

ABRASIVE MATERIALS.

DIATOMACEOUS DEPOSITS OF NORTHERN SANTA BARBARA COUNTY, CAL.

By Ralph Arnold and Robert Anderson.

INTRODUCTION.

During the summer of 1906 the writers, with the assistance of H. R. Johnson, made a more or less detailed survey of the Lompoc and Guadalupe quadrangles, California, embracing the Santa Maria oil field of northern Santa Barbara County, to determine the areal distribution and structure of the oil-bearing formations within their boundaries.[a] The diatomaceous deposits that were examined during the course of the investigations occur in such practically inexhaustible quantities in proximity to railroad and ocean transportation facilities that they were deemed worthy of description in this bulletin.

Although these deposits have been known locally for a long time and have received brief notice in such publications as Mineral Resources of the United States and in the reports of the California State Mining Bureau,[b] yet there is a general lack of knowledge in regard to their importance, as is shown by the absence of any mention of them in the standard text-books, where much smaller deposits are emphasized.

Infusorial earth, tripoli, or diatomaceous earth, as the same material is variously called, is of widespread occurrence in the California coast ranges and is found unaltered in great abundance in northern Santa Barbara County, where it is usually known by the name of diatomaceous earth or "chalk rock." The former designation is a very proper one to apply, as the formation is almost entirely made up of the skeletons of minute organisms called diatoms. These are

[a] A preliminary report by the writers on the geology and oil occurrence in this region is being published by the United States Geological Survey as Bulletin No. 317.

[b] For a brief account of the various diatomaceous deposits of California see The structural and industrial materials of California: Bull. California State Min. Bur. No. 38, 1906, pp. 289-296.

one-celled plants that adapt themselves to a wide range of conditions of depth and temperature in fresh and salt water and secrete siliceous casings or frustules around their organic material. They must have lived in extreme abundance in the ancient sea, for it is evident that the deposit was built up by the little shells of these plants which dropped to the sea bottom. The name "chalk rock" is inappropriate, for although the deposits closely resemble soft chalk in appearance they are made of silica instead of calcareous material. Examination with a hand lens almost always reveals a large number of the round forms of the diatom shells thickly embedded in the shale, many of them in a very good state of preservation. In some of the material they can be plainly made out with the naked eye. Here and there in petroliferous portions of the diatomaceous shale, individual diatoms will be seen completely filled with petroleum.

GEOLOGIC RELATIONS OF THE DEPOSITS.

By far the greater part of the diatomaceous material occurring in the territory under discussion is found in the Monterey (middle Miocene) formation. Such is the age of the deposits in the hills south and north of the Santa Ynez River, in the Burton Mesa, Casmalia and Santa Maria oil field areas, and in the region northeast of Santa Maria Valley and Sisquoc River.

Fairbanks[a] also reports diatomaceous earth in the Monterey formation south of Morro Bay, northeast of Port Harford, north of Pismo, and southeast of Edna, in San Luis Obispo County. The principal deposits are found toward the top of the Monterey, those in the lower portion being local in extent. The soft material is usually found in series of beds of considerable thickness, in which are a few beds of impure shale and some limy layers, the latter being common toward the bottom of the Monterey. All gradations from the soft earthy diatomaceous material to the hardest of black flints may be found, in some places within very short distances, thus indicating the extreme localization of the conditions that produced the harder varieties from the unaltered deposits.

Diatomaceous shale is found in the lower part of the Fernando formation, which overlies the Monterey unconformably, in the region between the head of Howard Canyon and Sisquoc and at one or two places along the north side of the Casmalia Hills. This portion of the Fernando is doubtless of upper Miocene age and is the equivalent of the Pismo and Santa Margarita formations described by Fairbanks, which contain diatomaceous earth in the region north of Arroyo Grande, southeast of Edna, and along Salinas River as far up as Rinconada Creek, all in the San Luis quadrangle.

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[a] Fairbanks, H. W., Description of the San Luis quadrangle: Geologic Atlas U. S., folio 101, U. S. Geol. Survey, 1904, p. 14.

LOCALITIES OF DIATOMACEOUS DEPOSITS.

REGION SOUTH OF SANTA YNEZ RIVER.

South of Lompoc. The only deposits of diatomaceous earth in northern Santa Barbara County that have been put to use occur just south of Lompoc, in the foothills of the Santa Ynez Range, east of the canyon of San Miguelito Creek. From the edge of the hills at Lompoc for a distance of 2 miles or more to the south the hills are formed of soft white diatomaceous earth in a very pure state. It is directly at the surface, can be quarried with the utmost ease, and is ready for shipment on removal from the quarry. In some places the material is in great soft masses, in which the bedding can not be recognized except by the characteristic weathering into flaky layers parallel with the original bedding planes. Elsewhere it is more compact and in thin beds varying from half an inch to 2 or 3 inches in thickness or in massive beds. The beds are tilted and in conformity with the much-disturbed hard beds of flinty shale of the lower portion of the Monterey formation, of which the whole series is a part. In places the diatomaceous, earthy horizon is traversed by thin laminæ of hard brown brittle shale. There must be at least 3 square miles over which the diatomaceous shale is exposed, and the thickness in some places reaches several hundred feet.

It may be mentioned in passing that some thin deposits of volcanic ash, comprising over the whole area a large amount of material, are interbedded with the diatomaceous earth in this region. The ash is of a siliceous variety, probably corresponding in composition to an acidic lavalike rhyolite. It is soft, pulverulent, of a lustrous grayish color, slightly more gritty than the tripoli, and very homogeneous. Its somewhat coarser nature might make it valuable for uses to which the diatomaceous earth is unsuited. It is worthy of note that large quantities of volcanic ash under the designation of pumice are imported annually from the Lipari Islands, in Italy, for use as abrasive material.

Two quarries are in active operation at Lompoc, that of Balaam Brothers and that of the Magne-Silica Company, of Los Angeles, and considerable quantities of the diatomaceous earth are shipped to Los Angeles and elsewhere. Active preparations are being made for the installation of a plant at Lompoc for the treatment of the earth.

Southwest and west of Lompoc. The outer portion of the hills southwest of Lompoc, along the southern border of the Lompoc Valley, is composed of soft white diatomaceous shale that is the westward continuation of the deposit just noted. It is of great purity and of such extent and thickness that it will afford an almost unlimited field for development. It would be difficult to estimate

the area covered, but it is many square miles. It forms a fringe to the hills, structurally overlying the hard, contorted lower Monterey shale that forms the greater portion of the hills for several miles back from the valley. On the sides of the canyon followed by a road into the hills 4 miles west of Lompoc about 1,000 feet of these beds are exposed with a steep northward dip toward the valley. It is probable that a considerable portion of the sand-covered hills west of this road as far as Surf, on the shore of the Pacific, is occupied by the soft shale of this series. The covering of sand is thin.

San Julian Rancho.—Diatomaceous shale, white and fairly pure, occurs interbedded with hard limestone and flinty shale at the base of the Monterey formation just north of El Jaro Creek at the point where it joins Salsipuedes Creek, on the northern border of the San Julian Rancho, in the foothills of the Santa Ynez Range. The amount present is small compared with the deposits higher up in the formation, as near Lompoc. In general, the lower half of the Monterey is barren of soft unaltered diatomaceous beds and the upper half is almost entirely composed of them. At least one area of pure flaky diatomaceous earth occurs near the head of Ytias Creek, but the region has not been carefully traversed. It is not probable that any very extensive area of it occurs here.

Other deposits.—Diatomaceous deposits are exposed along the road that follows Santa Ynez River east of Lompoc, on the point of the hills a mile southeast of the mouth of Salsipuedes Creek, and on the point near the western edge of the Santa Rosa grant. At these places the material forms a cap overlying the hard shales, but there is no great area of it.

BURTON MESA.

Burton Mesa is a wide, flat terrace of Monterey shale capped with a horizontal covering (about 25 feet deep) of recent sand and gravel. Along the northern border of the mesa and up the canyons running into it from the northwest and from the southeast are exposed white diatomaceous deposits, and this material constitutes the bulk of the northeastern portion of the mesa. Earth of a very fine quality forms the eastern side of the big canyon next east of Pine Canyon, from 5 to 8 miles northeast of Lompoc, and thence eastward to the point where the mesa merges into the hilly region south of Harris the valleys dissecting the terrace show that the whole region is composed of this material. The earth continues into the hills farther east, as described under the next heading. Good exposures in which the deposits may be examined occur along Santa Lucia Canyon and the valleys running into it. The material is of very light weight and soft, but yet compact. The bedding is thin, but as the earth is very homogeneous the bedding planes or changes from one bed to another

are not marked. A block may be split into flat plates of almost any degree of thinness. Santa Lucia Canyon cuts across the strike of the beds, which dip at a very low angle, about 12° on the average, toward the northeast. The thickness of the series within the limits in which it consists of pure diatomaceous earth is at least 2,000 feet.

The beds exposed along the northern edge of the mesa east of a point 2 miles from the ocean are similar, and it is probable that the region between this point and Santa Lucia Canyon, comprising the whole northeastern corner of the mesa, is composed of the same material. The area so included is at least 12 or 15 square miles in extent.

HILLS BETWEEN SANTA YNEZ AND LOS ALAMOS VALLEYS.

South of Harris.—The ridge of hills between the Mission La Purisima grant and Harris is composed of the upper part of the Monterey formation, which is overlain by more recent sand deposits on the flanks of the ridge. The new road from Lompoc to Harris exposes a thickness of at least 2,400 feet, which is almost entirely soft white shale composed of diatom remains. The beds dip northward at angles of 20° to 40°. Some of the material is of less pure quality than the best, and there are a few layers of brown brittle shale or yellowish-white porcelainlike shale, but the great bulk of it would be very suitable for economic use. It is extremely soft, and blocks of any size or shape can be cut out. A knife or saw or other cutting instrument will go through it just as through soft chalk. The same is true of the shale of the other occurrences mentioned in this paper.

Similar diatomaceous earth composes the whole ridge west of the new road as far as Burton Mesa. Locally it is covered by terrace sand, but this is only a thin capping a few feet in depth. There is an available area of at least 7 or 8 square miles of the earth, and when the thickness of the series is considered it becomes evident that a vast amount of the material is present.

Between Cebada Canyon and La Zaca Creek.—In most of the hilly region between Cebada Canyon and La Zaca Creek, for an extent of over 30 square miles, the diatomaceous shale predominates as the surface formation. Much of it is somewhat altered to impure varieties that would not be the best for economic purposes, but areas of many square miles are covered by deposits hundreds of feet thick that are of excellent quality. Areas of especially good material lie just north of Santa Rita all along the ridge for many miles west of Redrock Mountain and over the hills north, northeast, and southeast of that mountain. The thickness of the series that is exposed, all of which seems to be with little doubt of diatomaceous origin, whether now remaining in the original soft state in which it

is fit for commercial uses or altered to harder varieties, is at least 4,500 feet.

Hills south of Santa Rita.—Diatomaceous deposits covering several square miles lie on the southern flanks of the hills south of Santa Rita, the series attaining a thickness of several hundred feet and being finely exposed in some of the cliffs on the north side of Santa Ynez River. These deposits are underlain by hard shales, and it is difficult to outline areas in which the one occurs without the other.

VICINITY OF SANTA YNEZ.

Hills of diatomaceous earth are exposed locally about 1½ miles northwest of the Santa Ynez Mission and are readily seen from the valley where the mission stands. The shale is probably of considerable extent here, but is covered for the most part by thin, geologically recent sand deposits.

Soft shale occurs locally 3 miles and again 4 miles southeast of Santa Ynez, about a mile north of the river.

VICINITY OF CASMALIA.

The hills south of Casmalia are composed of white diatomaceous shale interbedded with slightly brittle layers in smaller amount. The canyon, followed by the road due south of Casmalia over to Burton Mesa, exposes a great amount of pure soft earth of a very good quality. This extends eastward under the terrace sands and is exposed again in the next canyons to the east. The sand deposit is not deep, and the tripoli earth is very near the surface over an area of 5 to 10 square miles.

East of Casmalia the deposits above noted continue over an equal area, being covered in some places by the terrace sand, but outcropping in all the canyons and forming the surface over the greater portion of the region. A good quality of shale is exposed along the road from Casmalia to Harris Canyon and on the ridge north of it. Some stretches are occupied by hard or impure shale that is unsuitable for quarrying, but these are only patches. Material of an especially good quality is exposed in large amounts on the southwestern flanks of the ridge running southeastward from Schumann toward Divide. The beds in general are only gently upturned and have a thickness amounting to many hundred feet.

On the northeast side of Schumann Canyon the deposits above mentioned have their continuation. In the low hills just north of Casmalia diatomaceous shale of rather poor quality occurs, but beginning at Schumann and running northwestward is a belt of excellent earth on the southwest side of the high ridge bordering the

Santa Maria Valley. The quality is especially good 2 miles northwest of Schumann, on the south side of this ridge. This deposit is at the summit of the Monterey formation, and just above it on the ridge the overlying Fernando beds have a similar diatomaceous character, although of less purity. The total area of fine diatomaceous material in this region would not exceed 2 square miles.

REGION OF THE SANTA MARIA OIL FIELD.

Something over 1 square of mile of Monterey diatomaceous shale is exposed in the region of the Santa Maria oil field southeast of Orcutt. These deposits were all covered at a not very remote period of geologic time by Fernando or later sediments which have been removed by erosion in the canyons, exposing the shale beneath. The beds are considerably tilted and jointed over most of the area, but in the region of the Pinal wells west of Pine Canyon deposits of fairly pure material of considerable thickness are exposed in the road cuts.

CANADA DEL GATO AND SISQUOC AREA.

Diatomaceous shale is found in the Fernando formation (of upper Miocene age in this part of the formation) in the region between the head of Howard Canyon and a point on the plateau south of Foxen Canyon about 2 miles southeast of Sisquoc post-office. The area over which the diatomaceous shale is exposed is about 5 miles long, with an average width of about 1½ miles, thus comprising 7½ square miles. The deposits vary in thickness from 60 to about 300 feet, and over a considerable portion of the territory lie almost horizontal. Along the southern border of the area the beds dip at angles as high as 35°. The material in this area is not so pure as the diatom shale found in the Monterey (middle Miocene), a fact that, coupled with its remoteness from the railroad, renders it unlikely that this deposit will be of economic importance for a long time, at best.

MOUNTAINS NORTHEAST OF THE SANTA MARIA VALLEY.

Soft, flaky diatomaceous shale occurs on Tepusquet Creek about 2 miles up from the Santa Maria Valley. Soft white shale is also found near the head of Rattlesnake Canyon about 2 miles south of Tepusquet Peak, and again south of Labrea Creek 2 miles northeast of its junction with Sisquoc River. But this shale is of inferior quality to that at previously mentioned places, nor is it comparable in thickness or extent. The major portion of these mountains is composed of strata older than the upper part of the Monterey formation—than that part, in other words, in which the soft shale occurs most abundantly.

SAN LUIS QUADRANGLE.

Diatomaceous deposits occur in the Monterey, Pismo, and Santa Margarita formations (the last two the equivalent of the lower Fernando in the Lompoc quadrangle) in the San Luis quadrangle,[a] immediately north of the Guadalupe quadrangle. The principal localities, according to Fairbanks, are on the mountains back of Pismo, in the region of Arroyo Grande, and along the hills bordering the south side of the San Luis Valley. Another bed of considerable thickness occurs on the slope of the San Luis Range south of Morro Bay, and similar deposits appear at various points along Salinas Valley, extending as far up as Rinconada Valley. These diatomaceous deposits are white and of chalky texture, as at the typical localities in the Lompoc quadrangle.

PHYSICAL AND CHEMICAL PROPERTIES

Diatomaceous earth when pure is white or gray in color, light in weight, and easily pulverized to a fine powder. Owing to the angular nature and hardness of its component particles it has valuable abrasive properties. It also has great absorptive powers, but is very resistant to weathering. Chemically it is composed essentially of opaline or colloidal silica and water, in general associated with minor quantities of alumina, iron oxide, lime, and magnesia as impurities. Diatomaceous earth is not soluble in acids under ordinary conditions, but is easily dissolved in the stronger alkalies. As chalk, with which diatomaceous earth is sometimes confused, is soluble in acid, the two may be distinguished by the acid test.

The following table gives 3 analyses of samples of the shale (slightly hardened diatomaceous earth) from the Lompoc quadrangle, together with analyses of similar diatomaceous material from other localities:

Analyses of diatomaceous earths or shales.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Silica (SiO_2)	65.62	86.92	72.50	86.89	86.90	80.53	80.66	81.53	84.15
Alumina (Al_2O_3)	....	4.27	11.71	2.32	4.09	5.89	3.84	3.43	1.40
Iron oxide (Fe_2O_3)	....	....	2.35	1.28	1.26	1.03	....	3.34	.70
Lime (CaO)	....	1.60	.32	0.43	.14	.35	.58	2.61	1.75
Magnesia (MgO)	....	Trace.	.83	Trace.	.51	....	....	....	1.10
Alkalies (K_2O+Na_2O)	....	2.48	1.88	3.58	1.18	....	....	2.59	....
Water (H_2O)	11.00	5.13	9.54	4.89	5.99	12.03	14.04	6.04	10.40
	....	100.40	99.13	99.39	100.07	99.83	99.12	99.54	99.50

1. Soft shale, Harris, Santa Barbara County, Cal. Analyst, W. T. Schaller, 1907.
2. Porcelain diatomaceous shale, Point Sal, Santa Barbara County, Cal. Fairbanks, H. W., Bull. Dept. Geol., Univ. California, vol. 2, 1896, p. 12. Specific gravity 2.12.
3. Soft shale, Orcutt, Santa Barbara County, Cal. Analyst, W. T. Schaller, 1907.
4. Monterey, Monterey County, Cal. Lawson, A. C., and Posada, J. de la C., Bull. Dept. Geol., Univ. California, vol. 1, p. 25. Specific gravity 1.8–2.1.
5. Fossil Hill, Nevada. Bull. California State Min. Bur. No. 38, 1906, p. 28.
6. Lake Umbagog, New Hampshire. 7. Morris County, New Jersey. 8. Popes Creek, Maryland. Merrill, G. P., Rept. U. S. Nat. Mus. for 1899, p. 220.
9. Hanover, Germany. Bull. California State Min. Bur. No. 38, 1906, p. 28.

[a] Geologic Atlas U. S., San Luis folio, No. 101, U. S. Geol. Survey, 1904, p. 14 and economic geology sheet.

USES.

The uses to which infusorial earth can be put are constantly being found to be more numerous, and the methods for its application are developing. Formerly it was employed solely for abrasive purposes, and this use has been extended in the manufacture of polishing powders, scouring soaps, etc. But its principal uses are now others. It is of value in the manufacture of dynamite from nitroglycerine, owing to its porosity, which makes it a good absorbent. Being a poor conductor of heat and very light, it is valuable for use in the manufacture of packing for safes, steam pipes, and boilers and of fireproof building materials such as hollow bricks for partition walls, floors, etc., solid bricks, furnace bricks, and tiles; also as a base in the manufacture of cements suitable for withstanding fire and heat. On account of its porous yet compact character it makes a good filtering substance, and is so used commercially. This use is facilitated when the tripoli can be obtained in compact blocks of the required size. The California product is very easily cut into any shape desired. Tripoli powder is also used in the manufacture of plaster. Some of the earth from the Lompoc region, it is said, is sent to a large neighboring refinery for use in the refining of beet sugar. An interesting use to which the raw material is put in the Lompoc region and also at Monterey, farther north on the California coast, is in the construction of buildings. The shale is easily quarried into smooth blocks, which, owing to their light weight, can be readily placed in position. A number of buildings have been very successfully constructed in this way. The shale blocks are compact and yet elastic under changes of temperature, seem to possess sufficient strength, and owing to the siliceous composition of the material are very resistant to weathering. Such building material would be finely adapted to regions subject to earthquakes, owing to the probable lesser effects of shocks on so light a substance and the smaller amount of damage that would result from falling materials.

PRODUCTION IN THE UNITED STATES.

Infusorial deposits occur in many States. Those producing it for economic use in 1903 were, in the order of importance, together with the number of concerns engaged in its exploitation, Missouri (3 producers), Virginia (2), New York (2), California (3), Maryland (1), Georgia (1), Massachusetts (1), New Hampshire (1), Florida (1). In 1904 the order changed somewhat, as follows: Missouri (2 producers), Maryland (1), California (2), Virginia (1), Florida (1), New Hampshire (1), New York (1), Massachusetts (1), and Georgia (1). The amount and quality of the material in California warrants the prophecy that it will lead in the production before long and supply enough to make it unnecessary to import any such products from abroad.

The following table is taken from the Mineral Resources of the United States for 1905, published by the United States Geological Survey:

Production of infusorial earth in the United States from 1880 to 1905.

Year.	Quantity in short tons.	Value.	Year.	Quantity in short tons.	Value.
1880	1,833	$45,660	1893		$22,582
1881	1,000	10,000	1894	2,584	11,718
1882	1,000	8,000	1895	4,954	20,514
1883	1,000	5,000	1896	3,846	26,792
1884	1,000	5,000	1897	3,833	22,385
1885	1,000	5,000	1898	2,733	16,691
1886	1,200	6,000	1899	3,302	25,302
1887	3,000	15,000	1900	3,615	24,207
1888	1,500	7,500	1901	4,020	52,950
1889	3,466	23,372	1902	5,665	53,244
1890	2,532	50,240	1903	9,219	76,273
1891		21,988	1904	6,274	44,164
1892		43,655	1905	10,977	64,637

COMPARISON WITH OCCURRENCES ELSEWHERE.

Infusorial earth occurs at widely separated points in other parts of the world. One of the largest and commercially best developed deposits is in northern Germany, where there are beds of this material varying from 20 to 50 feet in thickness from which the earth is quarried extensively, dried and prepared for market, and shipped to all parts of the world. There is a famous deposit at Richmond, Va., but considerable clayey material is mixed in with the deposit of diatoms, the analysis showing 70 per cent of silica, a considerable quantity of alumina, and some iron oxide. The bed attains a thickness of 40 feet in places and extends many miles. Other deposits over 30 feet thick occur at Bilin, Bohemia, and in Aberdeenshire, England. It can be readily seen that the quantity of infusorial earth at these places can not compare with the vast amount to be found in California.

IMPORTS.

Some infusorial earth is imported into the United States every year, being classed with the so-called rotten stone widely used in the manufacture of polishing substances. In past years the value of the imports of tripoli and rotten stone has approximated closely the value of the tripoli produced in this country, but the amount of the imports is declining with the increase in home production. The value of the imports in 1902 was $39,926; in 1903, $34,977; in 1904, $23,022, and in 1905, $18,986, as given in the Mineral Resources reports of the United States Geological Survey.

SURVEY PUBLICATIONS ON ABRASIVE MATERIALS.

The following list includes a number of papers, published by the United States Geological Survey or by members of its staff, dealing with various abrasive materials:

Chatard, T. M. Corundum and emery. In Mineral Resources U. S. for 1883–84, pp. 714–720. 1885.

Eckel, E. C. The emery deposits of Westchester County, N. Y. In Mineral Industry, vol. 9, pp. 15–17. 1901.

Fuller, M. L. Crushed quartz and its source. In Stone, vol. 18, pp. 1–4. 1898.

Hidden, W. E. The discovery of emeralds and hiddenite in North Carolina. In Mineral Resources U. S. for 1882, pp. 500–503. 1883.

Holmes, J. A. Corundum deposits of the southern Appalachian region. In Seventeenth Ann. Rept., pt. 3, pp. 935–943. 1896.

Jenks, C. N. The manufacture and use of corundum. In Seventeenth Ann. Rept., pt. 3, pp. 943–947. 1896.

Parker, E. W. Abrasive materials. In Nineteenth Ann. Rept., pt. 6, pp. 515–533. 1898.

Pratt, J. H. The occurrence and distribution of corundum in the United States. Bulletin No. 180. 98 pp. 1901.

——— Corundum and its occurrence and distribution in the United States. Bulletin No. 269. 175 pp. 1905.

Raborg, W. A. Buhrstones. In Mineral Resources U. S. for 1886, pp. 581–582. 1887.

——— Grindstones. In Mineral Resources U. S. for 1886, pp. 582–585. 1887.

——— Corundum. In Mineral Resources U. S. for 1886, pp. 585–586. 1887.

Read, M. C. Berea grit. In Mineral Resources U. S. for 1882, pp. 478–479. 1883.

Turner, G. M. Novaculite. In Mineral Resources U. S. for 1885, pp. 433–436. 1886.

——— Novaculites and other whetstones. In Mineral Resources U. S. for 1886, pp. 589–594. 1887.

Woolsey, L. H. Volcanic ash near Durango, Colo. In Bulletin No. 285, pp. 476–479. 1906.

PHOSPHATES AND PHOSPHORUS.

PHOSPHATE DEPOSITS IN WESTERN UNITED STATES.

By F. B. Weeks and W. F. Ferrier.

INTRODUCTION.

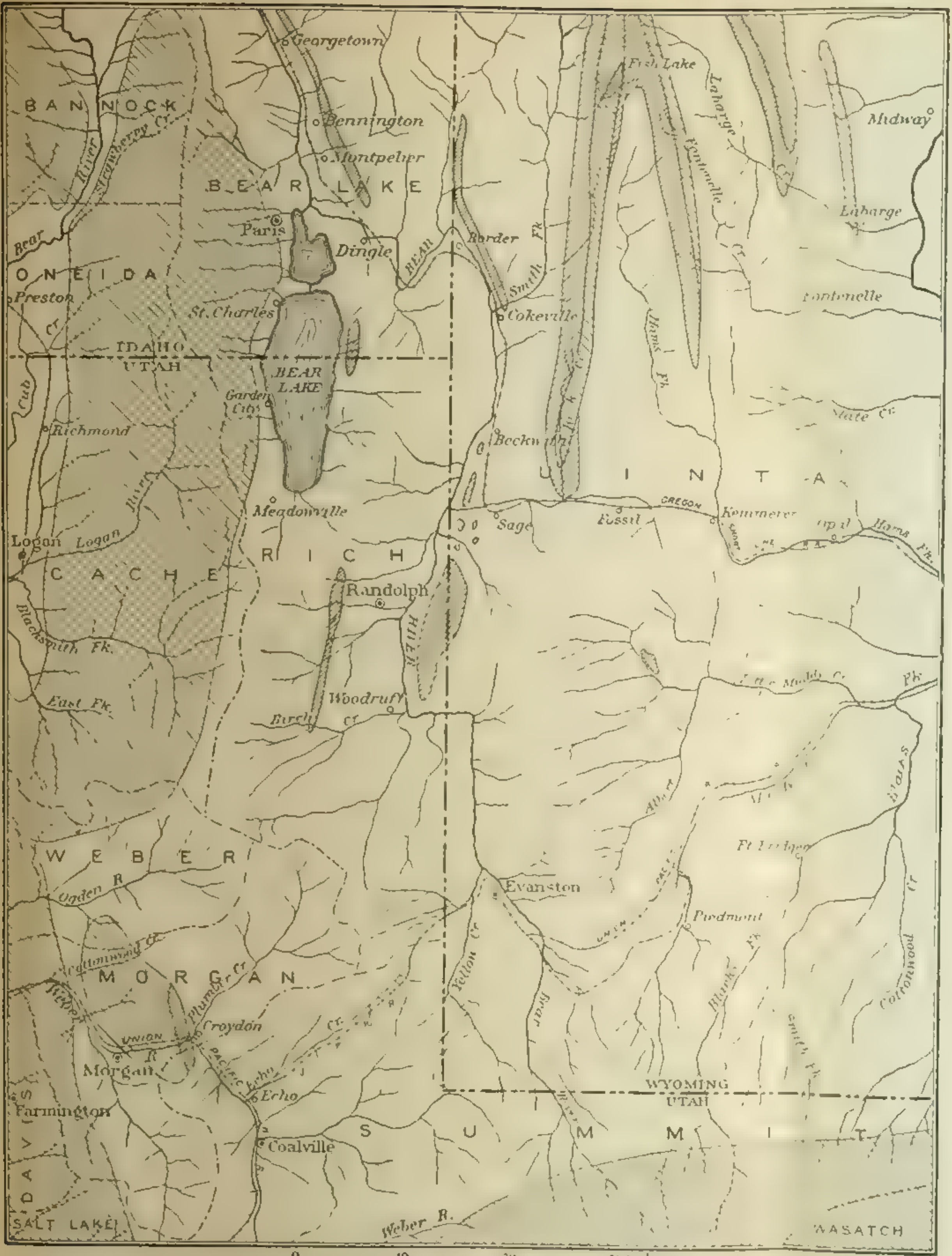
The present paper has been prepared as the result of ten days' field work by Mr. Weeks in October, 1906, and of previous reconnaissance surveys by Mr. Ferrier made to determine the distribution of the phosphate series, and of observations made by him in establishing and developing the mining operations at Montpelier, Idaho.

It has been thought advisable to bring together in this paper such general information relating to the phosphate deposits in the West as is now available, describing in some detail the localities where these deposits have been most extensively opened up and mined and which may serve as a general type, leaving for another occasion the more minute description of their various local characteristics and points of difference in geologic structure.

The discovery of these beds has opened up a new industry in the West, the future of which is largely dependent on the granting of such rates by the railroads as will enable the manufactured product or raw material to be sold at a profit in Australia, Honolulu, Japan, and the Middle States, the home market on the Pacific coast being at present a somewhat limited one.

GENERAL DESCRIPTION.

Within the last few years it has been found that the upper Carboniferous rocks of the central Cordilleran region include a series of oolitic beds containing a variable percentage of P_2O_5. These beds are known to occur over a considerable area in southeastern Idaho, southwestern Wyoming, and northeastern Utah. Prospecting has been carried on at a number of widely separated localities. The strike of the beds follows the general northwest-southeast trend of the ranges along which they outcrop.



Pre-Upper Carboniferous

Upper Carboniferous (Phosphate beds near base)

Post-Upper Carboniferous

MAP OF PARTS OF IDAHO, WYOMING, AND UTAH, SHOWING LOCALITIES OF UPPER CARBONIFEROUS ROCKS CONTAINING PHOSPHATE BEDS

Compiled from field notes and published maps

Silurian:
  Thin-bedded limestone, where present.
Ordovician:
  White and green quartzites.
  Light-colored, generally thick-bedded limestone.
Cambrian:
  Thin-bedded blue and gray limestone.
  Quartzites, mainly white in some areas, purple in others.

In portions of the area some parts of this section are absent by reason of nondeposition.

Three quartzite series are thus shown to be present in parts of this region. Since the phosphate series occurs a short distance above one of these quartzites, it is important that the prospector be able to recognize its occurrence in the field. This can be done in one of two ways. If a person is familiar with the general characters of the upper Carboniferous fossils, he can readily recognize this part of the section as the limestones, especially those occurring in and overlying the phosphate beds are very fossiliferous and the fossils are well preserved. If this method is not practicable, he can start from a known base and work out for himself the sequence of the various beds. The maps of the Fortieth Parallel Survey and of the Hayden Survey cover parts of the known area and would be useful in selecting a starting point from which to make a detailed section. Owing to the intense folding and compression which the beds have undergone in some localities and their probable repetition by faulting, the latter method may be found difficult to follow.

The whole of this section is known to occur in Weber Canyon and to the north in Utah and Idaho. To the south of the Weber, in the Wasatch Range, the Cambrian limestones, the Ordovician quartzite, and the Silurian and Devonian limestones become thinner and in some places appear to be entirely wanting.

CARBONIFEROUS SYSTEM.

GENERAL DESCRIPTION.

As the phosphate series occurs within the Carboniferous rocks, a more detailed description of these strata will be given. They outcrop over considerable areas in eastern, central, western, and northern Utah, southeastern Idaho, and adjoining portions of Wyoming, and in northern Nevada. Their lithologic characters are very persistent, and the three subdivisions may be recognized in the above-defined area.

The limestones which form the lower division are generally massive and occur in bold and precipitous outcrops. In many places they are coarse grained and weather rough and in dark colors. They are also rather siliceous and contain some cherty layers and masses. This division is 2,000 feet or more in thickness.

At the top of the limestones the beds become sandy and the quartzite series generally begins with an alternation of sandy limestones and sandstone beds, and continues through several hundred feet of sandstone weathering red and yellow. These are succeeded by yellow, white, and gray sandstones and quartzites, the upper half of the series being quartzite, readily recognizable as such.

This quartzite in most places grades into a dark, rather coarse granular limestone—the Upper Coal Measures limestone of the Fortieth Parallel Survey. The upper part of this formation consists of yellow sandstone and sandy limestones which grade into a blue-gray compact limestone just beneath the phosphate beds. In these blue and gray limestones indistinct fossils weather out on the surface, but are difficult of determination. This portion of the section varies considerably in the character of sediments.

PHOSPHATE-BEARING SERIES.

The phosphate series consists of alternating layers of black or brown phosphatic material, shale, and hard blue or gray compact limestones. The limestones are in the main very fossiliferous, containing well-preserved forms of *Rhynchonella*, *Chonetes*, *Omphalotrochus*, and *Productus*, which are apparently the characteristic fossils of this horizon. The shales contain *Lingula* and lamellibranchs.

The phosphate series is in places about 90 feet thick. The beds vary in thickness from a few inches to about 10 feet, but where of this extreme width are in general broken by thin layers of shaly material poorer in P_2O_5. At the base the series begins with limestone, and as a rule 6 to 8 inches of soft brown shale overlies this basal limestone. Above is the main phosphate bed, 5 to 6 feet thick. This is almost entirely oolitic in structure and high in P_2O_5. Several other beds, varying in thickness from a few inches to about 10 feet, separated by 6 inches to 2 feet of limestone or shale, occur in the series. The beds of extreme thickness, as already mentioned, contain seams of shaly material, itself phosphatic, too thin to be separated from the pure oolitic material in mining. All the sections that have been examined show one and some of them two beds which are of commercial value. The other beds are not of sufficient thickness, nor of a grade which will pay to mine at present.

The phosphate series is overlain by a coarse-grained, locally brecciated limestone, for the most part in massive outcrops. Above this limestone is sometimes found 100 feet or more of nearly white limestone, but as a rule it is succeeded by a series of blue and gray limestones containing large spirifers and *Productus*. Next above is a series of red sandstones and shales containing brachiopods and lamellibranchs. Still higher in the section is a considerable thickness of blue, gray, and greenish limestones, which form the upper part of

the upper Carboniferous series, and in the Montpelier region there are siliceous limestones and red sandstones containing ammonites and other fossils of lower Triassic age.

GEOLOGIC STRUCTURE.

The geologic structure of the region under discussion is very complex. The strata have been uplifted, sharply folded and faulted, and partially buried beneath the overlap of later sediments. It has been noted, however, that the phosphate series has been very little disturbed or displaced by the movements which have affected the sedimentary section as a whole.

WASATCH RANGE.

In Weber Canyon, where the phosphate series occurs, there is in the underlying Weber quartzite a sharp anticlinal fold that develops into a thrust fault. This structure is not readily detected on account of the heavy wash and the overlap of later sediments.

BEAR LAKE PLATEAU.

The Bear Lake Plateau comprises the region east of Bear Lake and the area to the south represented on the maps of the Fortieth Parallel Survey as Bear River Plateau. It also represents the eastern side of the Wasatch uplift. The sharply compressed fold of the Weber Canyon section appears to extend through this area, as the Carboniferous beds where exposed are in general characterized by steep dips and local variations in strike. A similiar structure is reported east of the north end of Bear Lake.

CRAWFORD MOUNTAINS.

The Crawford Range extends from Bridger Creek in a southwesterly direction, with outliers to the north, including the Beckwith Hills north of Twin Creek. Veatch[a] considers the structure as a broken anticline with a syncline developed on the eastern slope. A fault of considerable displacement follows the eastern side of the range and probably extends to the north in the Sublette Range east of Cokeville.

SUBLETTE RANGE.

The Sublette Range is formed of a sharply compressed series of Weber quartzites and upper Carboniferous beds. On the eastern side of the range a fault of considerable throw occurs, bringing the Bear River Cretaceous beds against the upper Carboniferous. In the northern part of the range the dip flattens and the topography is much less rugged in character.

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[a] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 56, 1907.

PREUSS RANGE.

The Preuss Range extends from Bear Lake northward along the east side of Bear River Valley beyond the limits of the area shown on the map (Pl. IV). Only the southern part of this range was visited. Here the general structure seems to be that of a broken anticline. The western side of the fold is made up of the phosphate series and the higher strata of the "Permo-Carboniferous" and overlying Triassic beds. The eastern side of the fold is probably formed of the same series, though not so well exposed, and of overlying Jurassic shales, thin-bedded limestones, and sandstones, as shown by fossils from two localities.

DESCRIPTION OF VARIOUS LOCALITIES.

In that part of the Wasatch Range which lies east and south of Salt Lake City the phosphate series, so far as it has come under the writers' observation, does not attain the thickness seen at other localities, and the phosphate beds are too thin to be of economic importance.

WEBER CANYON, UTAH.

The Paleozoic section from the Cambrian quartzite to the top of the Carboniferous is exposed in Weber Canyon from Peterson, a station on the Union Pacific Railroad, to Croydon. From the lower tunnel to the upper tunnel between Morgan and Croydon the Weber quartzite is exposed. A short distance above the lower tunnel there is a sharp anticline in this series, somewhat broken. The canyon follows the trend of this anticline for about half a mile, and the red, yellow, and white quartzites form bold escarpments on both sides of the river. The quartzites grade into coarse sandy beds, weathering in rounded cliffs, and into thin-bedded cherty limestones. Near Robinson's ranch the beds are nearly perpendicular, and the fold appears to have become a thrust fault. The phosphate beds, which seem to have been involved in this thrust movement, appear in canyons several miles farther north, but at a considerable distance west of the line of strike of these beds on the south side of the canyon. About one-fourth mile below Robinson's house the phosphate series has been exposed on the south side of the canyon in a number of test pits.

The following section is exposed on the south side of the river:

Section of phosphate series in Weber Canyon, Utah.

1. Blue-gray limestone.
2. Phosphate bed.
3. White and gray limestone with many bands of phosphate varying in thickness.
4. Light-blue and gray limestones, siliceous and cherty; yellow calcareous and siliceous beds; and white limestone.

The detailed structure and sequence of the phosphate series here has not yet been fully worked out. Heavy wash covers the base of the hills, extending a considerable distance up their flanks, to a point where the phosphate beds have been opened not far above the basal limestone.

Some of the beds contain flattened nodules of a white, extremely fetid calcite, many of them of large size. These have also been observed at other localities, in beds above the main phosphate bed.

The dip of the strata in the above section is steep, varying from 45 to 60° to the east, with an average strike of N. 10° W. On the north side of Weber Canyon the beds are closely folded and there appears to be an overthrust by which the outcrop of these rocks bends somewhat to the west.

The phosphate series has been traced for some distance on both sides of the canyon by means of test pits and outcrops, but no extensive developments have been made.

The following is a section in Tunnel Hollow, 1 mile south of the section just given:

Section in Tunnel Hollow.

1. Blue-gray limestone.
2. Phosphate and interbedded limestone.
3. Alternating bands of shale and phosphate.
4. Blue limestone, yellow sandy beds, and gray limestones, containing spirifers, *Productus*, Bryozoa, etc.
5. Red shales and sandstones.

WOODRUFF, UTAH.

The phosphate series at Woodruff, Utah, is largely concealed by heavy wash, and sufficient work has not yet been done to permit the making of a detailed section. The phosphate beds are exposed along Twelvemile, or Woodruff, Creek and Sugar Pine Creek, about 12 miles west of Woodruff. The best bed immediately overlies the basal limestone and averages about 5 feet in thickness. There is a series of smaller beds separated by limestone and shale, as observed at the other localities. The upper limestone, with characteristic large spirifers and *Productus*, is also present. Sandstone and quartzite, standing nearly vertical in places, crown the ridge on the west side of Twelvemile Creek toward the south end of the outcrop and also occur on Sugar Pine Creek. A careful determination of the fossils and comparison with those at Montpelier, Croydon, and other places is being made and the results will be given in a later paper. The strike of the beds varies locally, but a rough average would be about N. 15° E.; the dip is to the west at various angles, ranging from nearly horizontal to 60°.

SAGE, WYO.

The phosphate beds are seen again near Sage, Wyo., a station on the Oregon Short Line Railroad, about 24 miles northeast of Woodruff. The outcrop extends in a southerly direction a few miles to the southwest of the railroad. Some shipments have recently been made from Sage to the Pacific coast and work is now going on.

COKEVILLE, WYO.

The Sublette Range extends along the eastern side of the Bear River valley in this region. A bold escarpment of Carboniferous strata, which has been cut through by Smiths Fork, faces the valley opposite Cokeville, Wyo. The section as exposed on the north side of Smiths Fork is shown in fig. 18.

The quartzite beds are in vertical position with a tendency to overturn to the west. In the lower part of the upper Carboniferous

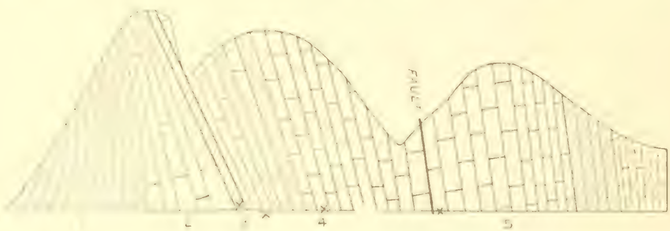

FIG. 18.—Sketch section 2 miles northeast of Cokeville, Wyo., on north side of Smiths Fork. 1, Weber quartzite; 2, upper "Coal Measures" limestone; 3, phosphate beds; 4, "Permo-Carboniferous" limestones and sandstones; 5, Cretaceous (Bear River) limestones and sandstones; X, fossil localities.

series the beds dip 65° E. for some distance, beyond which they stand nearly vertical. A fault occurs by which the Bear River (Cretaceous) is brought against the "Permo-Carboniferous," cutting out the Triassic and Jurassic, which according to Veatch[a] have together an average thickness of 5,500 feet in the region to the east. The strike of the beds follows the general trend of the range.

About 2 miles northeast of Cokeville, on the north side of Smiths Fork, the surface covering has been removed from the phosphate beds, which are exposed for a distance of 400 feet up the slope of the ridge, dipping 65° E. The uppermost layer of the series is a 6-foot bed of phosphate and below this, separated by 3 feet of brown shale and hard, blue limestone, is another bed 4 to 5 feet thick.

Two tunnels have been cut into the main bed, one about 35 feet the other about 50 feet in length. A square box chute with steel bottom has been built along the outcrop, extending down to storage bins near the base of the ridge. The rock is hard and requires considerable blasting. The material is shoveled into wheelbarrows,

[a] Veatch, A. C., Bull. U. S. Geol. Survey No. 285, 1906, p. 331.

taken to the platform at the tunnel mouth, and dumped into the chute, which conducts it by gravity to the storage bins. The phosphate will be dumped into wagons and hauled to the railroad at Cokeville, a distance of about 2½ miles over a level road. The property is controlled by the Union Phosphate Company. At the time of visit (October 12, 1906) three or four men were working in the tunnel and considerable material had accumulated awaiting the arrival of cars. No facilities for rapid handling of the material at the railroad had been provided. Development was progressing as rapidly as possible with the limited number of men employed.

THOMAS FORK, WYOMING.

There is an extensive exposure of the phosphate series low down on the flanks of the Sublette Range on the east side of Thomas Fork, which empties into Bear River at Border, Idaho, a station on the Oregon Short Line Railroad. As at Montpelier, the series is exposed in numerous small draws that cut across the strike, and also in Raymond Canyon, which penetrates the range. Between these points the outcrop is largely concealed by heavy wash. Several peculiar features characterize the series here and its detailed structure and geologic relations have not yet been fully worked out. At the south end of the exposure the beds stand at a high angle, in places almost vertical, and the best phosphate bed appears to be underlain by a hard, gray, exceedingly siliceous rock, apparently a cherty limestone. This has withstood the erosion of the softer strata and outcrops boldly, forming high vertical reefs along the range. Above the main phosphate bed there is the usual succession of limestones, shales, and phosphate. The structure is somewhat complicated owing to the faulting and folding of the strata. At the north end of the exposure, which is about 7 miles long, the beds in most places have a flatter dip, ranging from 45° to 60° W. The general strike at the south end is roughly north and south and at the north end of the exposure swings a little to the west. Some long cuts were made across the strata late in the fall of 1906, in order to expose their sequence, but snow came before the detailed study of the section was completed.

MONTPELIER, IDAHO.

The succession of strata in the range east of Montpelier, Idaho, is, in places, broken by folding and faulting and where this is the case the structure is difficult to follow, since not only does the faulting vary in amount of displacement, but the beds, particularly on the west side of the fold, contain numerous rolls which cause both the strike and dip to vary considerably within rather short distances. The intense compression to which these beds have been subjected has produced

in places a very remarkable fracturing by which they appear to be on edge, with a general north-south strike. The dip, however, is to the west at angles of 20° to 30°.

In the canyon of Montpelier Creek the lowest beds exposed are yellow, sandy limestone and sandstone and blue-gray siliceous limestone, which immediately underlie the phosphate series. The overlying limestones generally occur in massive outcrops. A prominent spur of the range extends nearly to the town of Montpelier and is formed of limestones and sandstones of upper Carboniferous and Mesozoic age. The lower portion of the upper Carboniferous series, including the phosphate beds, is exposed on the north side of Montpelier Creek, as shown in the accompanying section (fig. 19).

On the south side of Montpelier Creek the phosphate series is buried beneath the detrital slopes, and the outcrops of the phosphate beds

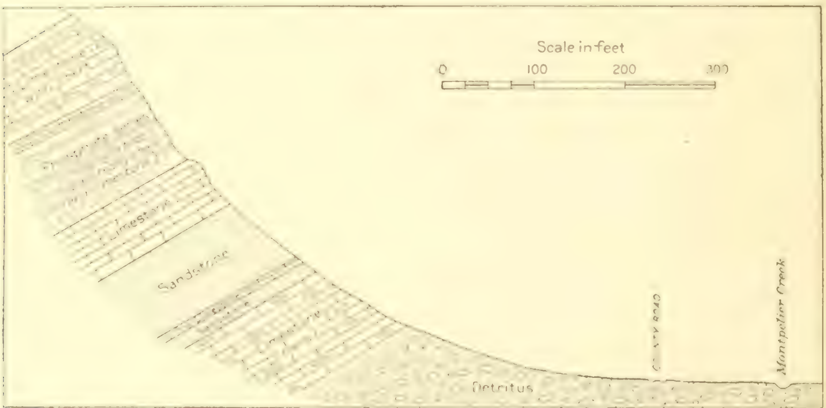

FIG. 19.—Section of Carboniferous strata on north side of Montpelier Creek, Idaho.

are exposed only in the numerous draws which cut across the strike along the range. Between these points the beds are not visible except where exposed by the large amount of development work which has been done, particularly on the Waterloo placer-mining claim. Their presence, however, is indicated by pieces of float and the characteristic darkening of the soil overlying them. Here the beds dip to the west at a low angle—about 20° to 30°. They are remarkably uniform in character over a wide area, rolling slightly, but showing no signs of any very serious disturbance. Erosion has removed the upper beds from a large portion of the ground, leaving extensive areas in which the main phosphate bed is now covered by only a 2-foot band of limestone and a few feet of shale and surface detritus. Here and there the top of the phosphate bed itself forms the surface of the ground and in places the bed has been completely eroded, leaving only the hard underlying cherty limestone. The band of limestone already referred to, which immediately overlies the main phosphate

bed, is locally shattered in a remarkable manner without displacement, the phosphate bed beneath being but little affected and both limestone and phosphate retaining their usual dip. The succession of the beds forming the phosphate series, as exposed in the workings of the Waterloo claim, is given in the accompanying typical section (fig 20).

On the south end of the claim and also at the north end in the higher ground the full width of the top phosphate bed, shown as

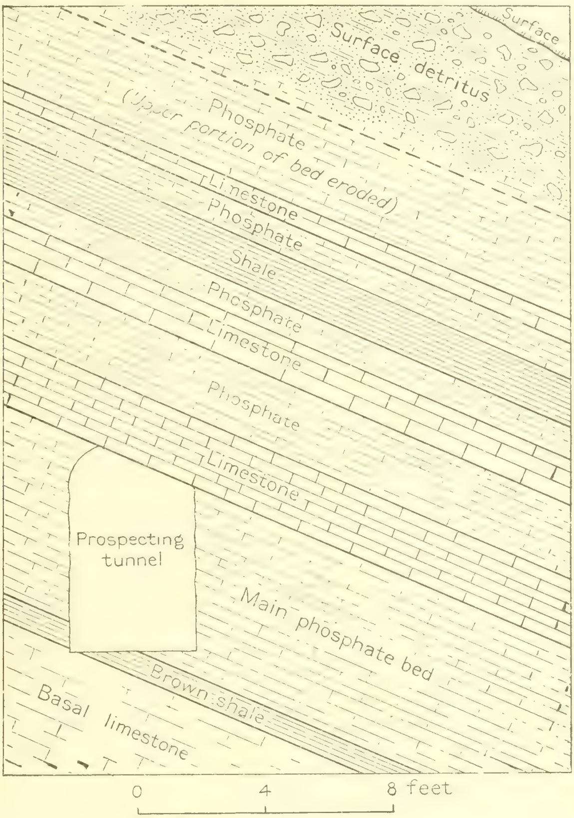

FIG. 20.—Typical section of lower portion of phosphate series, Montpelier, Idaho.

eroded in the section, is seen to be about 10 feet or more. It contains some large lime nodules, black and very hard, also thin layers of brown shale, and is overlain by a succession of alternating beds of limestone, shale, and phosphate, the phosphate being too thin or too low in grade to be profitably worked at present. This part of the series is best seen on the north side of Montpelier Creek, where it passes up into the massive limestones already mentioned. The dips here are in the main somewhat steeper.

From a practical standpoint the limestone immediately overlying the main phosphate bed at Montpelier is of considerable importance, being very uniform in character wherever found and containing abundant specimens of a coiled shell, *Omphalotrochus*, which, so far as observed, seems to be confined to this bed. This limestone or "cap lime," as it is called by the miners, is a valuable landmark in prospecting for the main bed of phosphate. It averages 2 feet in thickness, is dark gray in color, and very hard when freshly exposed, but rapidly weathers brown and finally disintegrates completely. Large blocks of it which have lain on the ground less than two years crumble to pieces when lightly struck with a hammer. In common with most of the other bands, it emits a strong bituminous odor when broken. Analyses show that some of these limestones contain several per cent of P_2O_5. Fossils are much more abundant in some than in others. In development work the position in the series of some of the beds can readily be determined from their fossils, even by one with no knowledge of paleontology. Such characteristic forms as *Omphalotrochus*, *Rhynchonella*, *Chonetes*, and *Productus* are abundant and well preserved. A remarkable specimen showing three large fish teeth in a portion of the jaw was recently discovered in the cap lime. The shales contain *Lingula* and lamellibranchs.

The main phosphate bed is the lowest one in the series at this locality and is just over the basal limestone, which contains much silica, in many places segregated as irregular bands and masses of chert. The phosphate layers are black to brownish in color and finely to coarsely oolitic in structure.

The beds rich in P_2O_5—for example, the main phosphate bed—are almost entirely oolitic, the small black granules being densely packed together with but little matrix material and effervescing but very slightly with HCl. The phosphate has a bituminous odor when freshly broken. As the number of oolitic grains, and therefore the P_2O_5 content, decreases, the beds assume more of the character of oolitic shales or limestones.

Several thousand tons of phosphate from the main bed at Montpelier, the whole of the material 5½ to 6 feet wide between the inclosing limestones being mined and shipped, showed a remarkably uniform content of P_2O_5, the average of a large series of analyses on carload lots giving a total of a little over 32 per cent P_2O_5, equivalent to 70 per cent bone phosphate. As the result of a careful experiment, it was found that a cubic foot of the phosphate in the main bed weighed 150 pounds. This gives 13.3 cubic feet to the ton.

The stratum varies considerably in hardness, the lower 2 feet being very hard and blocky and the upper portion being softer, with a more shaly structure.

In early days the dark shales associated with the phosphate were, owing to their bituminous odor, frequently taken to indicate the presence of oil or coal, and the deposits at Montpelier were filed on as coal lands and considerable work was done in the effort to find that material.

As the dip is low at this place, the beds are worked as an ordinary flat coal seam with pillar and stall. The phosphate is mined by both open-quarry and underground workings. A loading platform is placed at the foot of a gravity tramway running up the slope of the hill, the top of the platform being on a level with the main working tunnel. The phosphate rock is delivered at the platform in ordinary standard ore cars from both quarry and mine and loaded directly into the wagons through a chute. It is then hauled about 4½ miles to the Oregon Short Line Railroad at Montpelier and dumped into the cars through a door in a loading bridge built over the siding. It is now being shipped to the works of the San Francisco Chemical Company at Martinez, Contra Costa County, Cal., and there made into superphosphates to be used as fertilizers.

HOT SPRINGS, IDAHO.

The phosphate series is found at Hot Springs, Idaho, near the north end of Bear Lake on its east side, 14 miles south of Montpelier, forming the continuation of the series seen at the latter place and having the same general characters, but dipping at higher angles to the west. The deposits are extensive.

BENNINGTON AND GEORGETOWN, IDAHO.

To the north along the general line of strike the phosphate series is seen near Bennington, Idaho, about 5 miles from Montpelier, where it is apparently considerably broken and faulted, and again in a steep canyon some miles east of Georgetown, which is 11 miles northwest of Montpelier.

VICINITY OF SWAN LAKES, IDAHO.

About 4 miles east of Manson, a small siding on the Oregon Short Line Railroad, a mile south of the line between Bannock and Bear Lake counties, Idaho, the phosphate series is exposed in a high range of hills. The strata are much faulted and folded, but little development work has yet been done, and the detailed structure is therefore not yet satisfactorily worked out. The series has been traced for several miles along the flanks of the range, which is cut by deep gulches, and also, owing to the folding, is found on the high ground. The general line of strike swings more to the west than at

Montpelier, and the dips are to the west at widely varying angles. There is a bed of phosphate here which corresponds in its general character, thickness, and grade to the main bed at Montpelier and, at several places where it is opened up, dips from 20° to 30° to the west. It is overlain by a band of limestone in which *Omphalotrochus* and *Chonetes* have been recognized. Above this band of limestone there is the usual succession of beds of phosphate, limestone, and shale. In places this phosphate bed is faulted and apparently lies over a massive limestone in which a large *Productus* is found. Work is being undertaken to trace out the sequence and extent of the phosphate beds at this locality.

DEVELOPED PHOSPHATE DEPOSITS OF NORTHERN ARKANSAS.

By A. H. Purdue.

INTRODUCTION.

The field work for this paper was done in the latter part of August and the first part of September, 1906. Previous to this time (in the latter part of 1903) the writer made a visit to the developed deposits for the purpose of arranging for an exhibit of the phosphate rock and its products at the Louisiana Purchase Exposition. The company operating the mines and the fertilizer plant connected therewith freely assisted in preparing an exhibit and, among other things, shipped to the exposition a solid block of phosphate rock 4 feet wide, 8 feet long, and somewhat more than 4 feet thick. This block of stone attracted the attention of those who were interested in the fertilizers and phosphate deposits of the country and excited special interest in the deposits of Arkansas, an interest that justifies the preparation of the present paper.

The area over which the phosphate deposits of northern Arkansas occur is mentioned in the following reports of previous writers:

Owen, David Dale. First report of a geological reconnaissance in the northern counties of Arkansas, made during the years 1857 and 1858. 1858.

Penrose, R. A. F. Manganese; its uses, ores, and deposits: Ann. Rept. Geol. Survey Arkansas for 1890, vol. 1.

Hopkins, T. C. Marbles and other limestones: Ann. Rept. Geol. Survey Arkansas for 1890, vol. 4.

Branner, J. C. (State geologist). The lead and zinc region of northern Arkansas: Ann. Rept. Geol. Survey Arkansas for 1892, vol. 5.

Branner, J. C. The phosphate deposits of Arkansas: Trans. Am. Inst. Min. Eng., vol. 26, 1896, pp. 580–598.

Branner, J. C., and Newsom, J. F. The phosphate rocks of Arkansas: Bull. Arkansas Agr. Exp. Station No. 74, 1902.

Ulrich, E. O., and others. Zinc and lead deposits of northern Arkansas: Prof. Paper U. S. Geol. Survey No. 24, 1904, p. 100.

GEOGRAPHY AND HISTORY OF THE PHOSPHATE BEDS.

Geographic distribution of the beds.—The developed phosphate deposits of Arkansas are on Lafferty Creek, on the western edge of Independence County. The only point at which the beds are now worked is

about three-fourths of a mile east of White River and the same distance from the White River branch of the Missouri Pacific Railway. A spur extends from the main line up Lafferty Creek, past the quarry, and on to the old workings, which are about a mile to the northeast, on East Lafferty Creek. Although this is the only locality at which the deposits have been developed, they have a wide east-west extent, reaching from the town of Hickory Valley, 10 miles northeast of Batesville, westward at least as far as the town of St. Joe, in Searcy County, a distance of more than 80 miles in a direct line. This statement must not be taken to mean that phosphate rock outcrops throughout the whole of this distance or that all the deposits found are sufficiently large or of high enough grade to work with profit. It means that a phosphate bed, which is practically horizontal, outcrops in a winding line on the hillsides and in other places between the points mentioned. A phosphatic horizon can be traced westward to the western border of the State, but at no point west of St. Joe have phosphate rocks, in considerable amount, attracted the attention of geologists. Thin beds of phosphatic sandstone are found in the Devonian shales in the western part of Carroll County, on War Eagle Creek. While it is certain that prospecting for workable deposits would be useless throughout most of the distance over which the phosphate rock outcrops, it can confidently be expected that minable deposits other than those now known will be discovered, especially in the eastern part of the field.

Topography of the area.—The area near the developed deposits is much dissected by streams. The main line of drainage is White River, which here stands about 250 feet above sea level. Above the river on both sides are steep-sloping hills or almost perpendicular bluffs. The tributaries of White River flow southward in valleys that lie from 200 to 400 feet below the hills on both sides. Lafferty Creek, on which the developed deposits are located, flows in a valley that is 400 feet deep.

Discovery and history.—The following account of the discovery of the phosphate deposits of northern Arkansas has been furnished the writer by Dr. J. C. Branner, ex-State geologist of Arkansas:

> The first mention of the phosphate deposits of Arkansas was made by Owen, who spoke of the bed at St. Joe as a vein of ore containing iron and manganese (?).[a] Owen, however, did not recognize the material as phosphate rock. The next mention was made by Penrose in his manganese report.[b] He also failed to determine the true nature of the rock, and Doctor Wolff, of Harvard, was disposed to think it volcanic tuff. Hopkins noted the beds at several places, and mentions them in his marble report,[c]

[a] Owen, David Dale, First Report of a Geological Reconnaissance of the Northern Counties of Arkansas, made during the Years 1857 and 1858, p. 79.

[b] Penrose, R. A. F., Manganese; its uses, ores and deposits: Ann. Rept. Geol. Survey Arkansas for 1890, vol. 1, pp. 126–127.

[c] Hopkins, T. C., Marbles and other limestones: Ann. Rept. Geol. Survey Arkansas for 1890, vol. 4, pp. 212–213.

but he did not recognize them as phosphate rocks. I saw and made notes of several of the phosphate localities in 1890, but the rocks were not recognized to be phosphate beds until 1895, when I had analyses made here at Stanford University. That same year I went to Arkansas * * * and gathered the bulk of the information that enabled me to publish the paper brought out by the American Institute of Mining Engineers in vol. 26 of their Transactions.

What has been written concerning the phosphate deposits of northern Arkansas as such is to be found in the papers by Professor Branner and by Professors Branner and Newsom.[a] Inasmuch as the present paper deals with only a limited portion of the area over which the phosphates extend, those desiring a wider knowledge of the extent and nature of the beds are referred to these two papers.

GEOLOGY OF THE REGION.

In the area over which the phosphate deposits of northern Arkansas occur nothing but sedimentary rock is exposed at the surface. The ages, relations, and names of the formations in the eastern part of the area are given in the following section:

General section in phosphate region of northern Arkansas.

Carboniferous:
- Boone chert, including St. Joe marble.

Devonian:
- Chattanooga shale and Sylamore sandstone.

Silurian:
- St. Clair limestone.

Ordovician:
- Cason shale.
- Polk Bayou limestone.
- Izard limestone.

The above rocks will be briefly described, for the purpose of assisting those who may desire to prospect for phosphate rock.

Izard limestone.—This limestone, as described by Dr. T. C. Hopkins,[b] "is a smooth, fine-grained, compact, homogeneous, nonfossiliferous, evenly bedded limestone, breaking with a conchoidal fracture, and is mostly of a dark blue color, varying locally to buff, light and dark gray, and almost black."

This limestone occupies the lower part of the valleys in the region of the developed deposits. It constitutes the lower part of Penters Bluff and occurs along Lafferty Creek and its tributaries and at Phelps Spring, a half mile north of Cushman. This limestone varies considerably in thickness. According to Mr. Hopkins, 280 feet[c] at the base of Penters Bluff is Izard limestone, which reaches down to the

[a] Branner, J. C., The phosphate deposits of Arkansas: Trans. Am. Inst. Min. Eng., vol. 26, 1896, pp. 580–598. See also Branner, J. C., and Newsom, J. F., The phosphate rocks of Arkansas: Bull. Arkansas Agr. Exp. Sta. No. 74, 1902.

[b] Ann. Rept. Geol. Survey Arkansas for 1890, vol. 4, p. 109.

[c] This measurement is probably too great, according to Mr. E. O. Ulrich.

water's edge of White River. A mile and a half west of Cushman, on the point of the hill in the northern part of sec. 7, T. 14 N., R. 7 W., the limestone is 110 feet thick. On the south slope of Pumpkin Branch it is 130 feet thick; in the northwestern part of sec. 1, T. 14 N., R. 8 W., it is 210 feet thick. At least 50 feet of it is exposed along the lower part of West Lafferty Creek.

The Polk Bayou limestone.—This limestone immediately overlies the Izard limestone. It is everywhere present in the vicinity of the developed deposits, but is not so widespread over northern Arkansas as the Izard limestone. At Phelps Spring, just north of Cushman, it is 120 feet thick. Both limestones are exposed here, the spring issuing from the Izard. At the cave 1½ miles west of Cushman it is 130 feet thick. One-half mile north of the cave and across the hollow from it, in the northern part of sec. 7, T. 14 N., R. 7 W., it is 75 feet thick.

This limestone occurs in massive beds. In color it varies from a rather light gray at the basal portion to a brown, in some places a chocolate color, at the top. The texture is very coarse, the rock being made up of crinoid stems and other fossil fragments, bound together by crystals of calcite. Much-weathered specimens of this limestone present a spongy resistance to the blows of the hammer, and break up into coarse, sandlike material.

The Cason shale.—Within the area examined by the writer the rocks at the horizon of the Cason shale are of variable nature. It is at this horizon that the phosphate rocks herein considered occur. Usually somewhat more than 4 feet at the top consist of shale, or, in the outer part, of clay derived from the disintegration of the shale. The upper part of the shale is yellow to brown in color; the lower portion, which ranges in thickness from 2 to 14 inches, is green. In some places, as at the phosphate quarry later to be described, the shale contains a thin bed of low-grade iron ore. In other places it is manganiferous. Such samples as were tested were found to be phosphatic, and the rock is probably so everywhere.

The phosphate rocks of the region are associated with this bed of shale. All of the developed deposits here are below it, but in other places there are phosphatic beds above shale, which is presumably the same as this. The phosphate beds vary in character, ranging from those that are brown and sandy and of low grade to those that on fresh surfaces are bluish gray, apparently without sand, and of uniform texture and color. It is the latter that are worked. They will be more fully discussed later in the paper.

Manganese ore is at many places closely associated with the phosphate beds. So common, indeed, is the association of the two that débris of the manganese, which is always plainly perceptible where present, is a good guide in prospecting for phosphate rock.

The St. Clair limestone.—The St. Clair limestone lies above the Cason shale. In the vicinity of the developed deposits it is from 8 to 18 feet thick. It is a compact crystalline limestone, pinkish in color, and is composed largely of small fragments of crinoids and other fossils. The fossil fragments stand out on weathering, producing very rough surfaces. The St. Clair limestone is thought to be the only representative of the Silurian in the region.

The St. Joe marble and Boone chert.—Upon the St. Clair limestone rest rocks of Carboniferous age, known as the St. Joe marble and the Boone chert. The former is the older of the two, and is only locally present in the eastern part of the phosphate region. Where typically developed the St. Joe limestone occurs in layers from a few inches to 2 feet or more in thickness. Elsewhere it is usually a somewhat coarse-textured rock, and is gray at the lower and upper parts, while the middle portion is often red, but the rocks that occupy the stratigraphic position of the St. Joe in the locality under discussion are usually gray to dove-colored, compact, and contain large numbers of calcite seams. These beds may be the representatives of the St. Joe marble, and may therefore belong to an older Carboniferous formation.

The Boone chert is a heavy deposit of limestone, contains a large amount of chert, and is of wide extent over the southern part of the Ozarks. Where the St. Joe is absent in the region under discussion the Boone chert rests on the St. Clair limestone if this is present; if not it rests on the Cason shale, the chert lying immediately over the phosphatic deposits.

THE DEVELOPED DEPOSITS.

Location.—The developed phosphate deposits of northern Arkansas are confined to secs. 14 and 15, T. 14 N., R. 8 W., situated on Lafferty Creek, near the junction of East Lafferty and West Lafferty creeks, about 4 miles a little south of west of the town of Cushman, in Independence County. They are about 12 miles northwest of Batesville, the county seat, and from a half mile to 1½ miles from White River and the White River branch of the Missouri Pacific Railway.

History of the operating company.—The following history was furnished by Mr. F. S. Williams, secretary and manager of the company operating the mines:

In June, 1900, a company was organized under the name of the Arkansas Phosphate Company, for the purpose of developing the phosphate beds along Lafferty Creek, Independence County, Ark. After several months of prospect work it was found that the phosphates exist in sufficient quantities to justify extensive mining operations. A mining and milling plant was erected, several miles of railway spur were laid, and mining was begun. After only a few months of active operation the plant was destroyed by fire, which stopped

the work. A much larger plant is now nearing completion at Little Rock, to which the crude products of the mine will be shipped in the future, to be manufactured into various phosphatic and fertilizer products.

Little Rock was selected for the new plant because of its central location and its good railroad facilities. The company in the meantime has had its name legally changed to the Arkansas Fertilizer Company. The new plant will have an annual capacity of 40,000 tons, with a shipping capacity of 15 to 18 cars a day.

The company has mined to this time (October, 1906) about 10,000 tons of crude phosphate, of which about 2,250 tons have been produced within the last four months. The present output of the mine is approximately from 500 to 600 tons a month. The company is now manufacturing fine ground crude phosphate, acid phosphate, and a full line of other fertilizers made from Arkansas phosphates blended with ammoniates, potash, etc.

Description of developed deposits.—The deposits first developed are in a small ravine that enters East Lafferty Creek from the east, in the northern part of sec. 14, T. 14 N., R. 8 W. At this place the phosphate rocks outcrop on the hillsides at an elevation of about 500 feet above sea level, and have a low dip toward the west. The development extends for about half a mile on either side of the road that runs along the bottom of the ravine. The work at this point was done mainly by running adits into the hillside and mining out the rock, though some of the rock was obtained from open quarries.

The phosphate at this place occurs beneath a ledge of St. Clair limestone from 8 to 10 feet thick. The workings had been abandoned for three years when the writer last visited the place, and the exposures were more or less obscured. The bed that was worked here is about 22 inches thick, lying beneath a yellow to brown colored clay from 4 to 5 feet thick. Beneath the phosphate bed is a phosphatic sandstone, the thickness of which was not determined, but it rests upon the Polk Bayou limestone. The two phosphate beds are usually separated by a layer of manganiferous iron ore 1 or 2 inches thick.

Such exposures of the developed phosphate bed as were seen here showed that it had been considerably weathered and its original appearance much changed. The rock observed in the adits was soft and earthy and of a dark brown color, containing numerous small subangular fragments and closely specked by small, white grains. On examination under the magnifier the rock is found to contain large numbers of small, apparently sandy pebbles. Where exposed to the weather it is brown to yellow on fresh surfaces. Many of the old surfaces and joints are colored black with a thin coat of manganese stain. Weathering brings out thin shaly laminæ in some places.

The discovery of heavier deposits on Lafferty Creek, about a mile southwest of the above workings, led to their abandonment and the opening of mines at the new place. These deposits are on the east slope of the hill that lies between Lafferty Creek and White River, near its base. The following section shows the phosphate beds and their geologic relations:

Section containing phosphate beds.

	Ft.	in.
St. Clair limestone.		
Brown to black shale	2	0
Low-grade manganiferous iron ore	0	15
Green to dark clay shale	0	14
High-grade phosphate	4½-6	0
Manganiferous iron ore	0	2
Low-grade phosphate	4	0
Polk Bayou limestone.		

Only the upper phosphate bed is worked, the lower being considered of too low grade. At present the stone is worked by quarrying. The main quarry at the time of the writer's visit was 375 feet long by about 30 feet wide. An additional 150 feet at the north end was stripped, ready for quarrying. South of the main quarry there were two smaller ones, 150 and 225 feet, respectively, from the main quarry, thus making a total distance of 750 feet along which the deposit was opened. Besides the beds had been prospected by sinking shafts 480 feet farther south, at which point the dip of the beds brings the deposit below the creek. The beds outcrop at points north of the main quarry and have been prospected more or less for 1,000 feet along the hillside. The total distance, therefore, along which the beds at this place outcrop and are known to be workable is about 2,200 feet.

East of this point, on the opposite side of the creek, an adit 30 feet long has been run into the hillside. This adit was driven apparently for the purpose of prospecting the upper of the two phosphate beds, which at this place is 3 feet 4 inches thick. Beneath this, as at the main workings, there is a phosphate bed of lower grade, the thickness of which could not be ascertained at the time of the writer's visit, but it is probably about 4 feet.

As above stated, it is only the upper of the two phosphate beds that is now quarried for commercial purposes. This is a compact, homogeneous, light-gray rock with a specific gravity of about 3. At a distance it has the appearance of volcanic tuff. The color is due to small white particles that are thoroughly mixed with dark-gray material. The white particles appear to the unaided eye and under the magnifier as if they might be small fragments of bones. The dark-gray material is made up of particles of varying size, some so small that they can be seen only with the magnifier, others a quarter of an

inch in diameter. These particles are more or less angular, some of them strikingly so, making the stone distinctly conglomeratic in appearance. The stone emits an earthy odor. In order to determine whether the gray particles are really fragmentary material or concretions and also to ascertain the nature of the white fragments, a specimen was submitted to Dr. Albert Johannsen, of the United States Geological Survey, for microscopic examination, who reports as follows:

The thin section is made up chiefly of organic remains, perhaps fragments of bone, in a cement of calcite, with very little of an isotropic, deep purplish mineral, having an index very much less than Canada balsam—probably fluorite. The sections show no concretions; the calcite seems to be a filling between the fragments of bone.

A small portion of rock at the outer edge has been leached of lime by surface waters and when freshly quarried is dark colored. This is called by the quarrymen "black phosphate." It contains a considerable amount of water, to which the color is attributable, and is richer in phosphate than the remainder of the bed.

The lower bed is similar to the upper one, though darker in color, more compact, and not conglomeratic, so far as observed. The darker color is due to the smaller amount of the white material and possibly to a larger amount of iron or manganese, or both. It has a greenish tinge, which is suggestive of glauconite. This bed becomes very ferruginous in its upper part and is here, as in the old workings on East Lafferty Creek, separated from the bed above by a thin layer of manganiferous iron ore.

The following analyses of specimens of the rock were made in the laboratory of the United States Geological Survey. Number 1 was a specimen taken from the lower bed; Nos. 14-18 were specimens from the bed now being worked.

Analyses of phosphate rock from Arkansas.

No.	Where taken.	Phosphoric acid (P_2O_5).	Equivalent in calcium phosphate. ($Ca_3(PO_4)_2$).
14	4 inches from top of bed	25.86	56.45
15	Middle of bed	27.24	59.46
16	8 inches from bottom of bed	27.40	59.81
17	"Black phosphate"	32.60	71.06
18	Composite sample	29.18	63.70
1	From lower bed	13.46	29.38

Amount of the phosphate rock.—The aggregate thickness of the two beds at the quarries is from 8½ to 10 feet, but, as already stated, only the upper bed is worked at present. Somewhat more than one-half a mile west of the quarries, on the opposite side of the hill and above the railroad, the phosphate horizon is represented only by a bed of red calcareous shale 6 inches thick, overlain by brown, compact limestone 20 inches thick. Both of these beds are slightly phosphatic.

How far west of the quarries the bed now being worked will hold out is problematical, though it is reasonable to suppose that it will maintain a workable thickness at least halfway through the hill.

Opposite the quarry, on the east side of Lafferty Creek, an adit shows that the upper bed of phosphate is 3 feet 4 inches thick. Only development work can determine how far this thickness is maintained, but the fact that phosphatic débris occurs extensively on the undeveloped southern part of sec. 14, immediately to the east, indicates that this thickness might hold for a considerable distance. As stated above, the rock is about 22 inches thick in the northern part of sec. 14, where it was first worked.

Methods of working.—At the old workings on East Lafferty Creek the phosphate rock was worked by stripping and quarrying and running short adits into the hill on a level with the phosphate beds. At the present workings only the former method has been used thus far. The beds so outcrop as to permit the company to work by this method for some time if they choose to do so; but eventually it will be necessary to run adits into the hillside. Drilling is done by hand, and the rock is hauled in wagons to the opposite side of the creek, where it is loaded on the cars for shipment. Before shipment the "black phosphate" is dried by ricking up the rock and leaving furnaces at the bottom, in which fires are built. Much the greater part of the stone is not weathered and is shipped without drying.

ORIGIN OF THE PHOSPHATES.

The comparatively uniform thickness of the phosphate beds and their occurrence, within the locality considered, always at the same geological horizon, at once determine them as of sedimentary origin. If any further evidence for such origin is necessary, that furnished by the microscopic examination is conclusive. This examination determines the gray, pebblelike material not to be concretions (consequently waterworn material) and the white particles that constitute so large a part of the mass to be organic remains.

Doctors Branner and Newsom think that the beds are probably deep sea (though not abysmal) deposits, and that their phosphatic nature is probably due to "the droppings of fishes and other marine animals and to accumulations of organic matter that settled to the bottom of the quiet waters that covered this part of the world during Silurian and Devonian times."[a] But from the conglomeratic character of the rock brought out by microscopic examination it appears that the deposition of the phosphate beds took place in shallow water, having closely followed the shore line as it advanced landward. This is further shown by the fragmentary character of the organic mate-

[a] The phosphate rocks of Arkansas: Bull. Arkansas Exp. Station No. 74, p. 69.

rial, a character that was probably produced by wave action along shore, which ground up the shells or the bones, as they may have been. It would seem that the droppings of marine animals, as above suggested, might account in part for the phosphatic nature of the beds, but the presence of so large an amount of organic fragments suggests that wave action was probably its chief cause. The exact character of these organic fragments can not yet be stated. Although they appear to be fragments of bones, the probability that they are such is much reduced by the fact that beds are placed (at least tentatively) in the Ordovician, and the probability that they are Ordovician forces one to the conclusion that the fragments are more likely those of the tests of crustacea, which are known to be phosphatic.

AGE OF THE PHOSPHATES.

The phosphates of northern Arkansas have heretofore been considered as of Devonian age, though Professors Branner and Newsom suggest that phosphates of earlier age may occur.[a] The lithologic character of the limestone above the phosphate beds on Lafferty Creek and its tributaries led to the supposition that this is the St. Clair limestone, which is of Silurian age. Fossils collected from this bed and sent to Mr. E. O. Ulrich, of the United States Geological Survey, confirmed this supposition. Fortunately, Mr. Ulrich had already visited the locality himself, which makes his determination of the beds all the more reliable. Two lots of fossils from the limestone above the phosphate beds at two different places were sent to Mr. Ulrich, and in a letter concerning them he says:

> Both lots of fossils are unquestionably indicative of the St. Clair limestone. The species are mostly different in the two lots, but all are of Silurian types known to occur in the St. Clair.
>
> The phosphate along Lafferty Creek occurs, judging from your evidence and my own observations, in the equivalent of the Cason shale, which elsewhere in the vicinity of Batesville contains the manganese. * * * It was only last year that I had an opportunity to satisfy myself that the phosphatic deposits being worked along the east bank of Lafferty Creek were undoubtedly in shale intervening between the Polk Bayou and the St. Clair limestone.

The Cason shale is considered by Mr. Ulrich as of Ordovician age. Certainly the phosphate beds are not younger than Silurian.

PROSPECTING FOR PHOSPHATES.

As the phosphate rocks of northern Arkansas are usually covered by soil where they outcrop on the hillsides, a few suggestions to prospectors in search of these beds may be of advantage. As one passes up the hillsides of the deeper valleys in western Independence County he goes first over a compact, gray to dove colored, brittle

[a] The phosphate rocks of Arkansas: Bull. Arkansas Exp. Station No. 74, pp. 66, 67, 69.

limestone, that breaks easily under the blows of the hammer. This is the Izard limestone. Above this is a coarsely crystalline limestone, light gray at the bottom, but growing darker toward the top, until the upper portion is at some places almost chocolate colored. This is the Polk Bayou limestone. It is at the top of this limestone that the phosphate of the locality occurs. In case the St. Clair limestone is present it will be found above the phosphate; if not, the Boone chert (possibly the St. Joe marble) will be found above it. It is useless to look for phosphate above the base of the Boone chert or below the top of the Polk Bayou limestone. In case the rocks on the hillsides are all hidden, the position of the phosphate beds may be determined approximately by examining the débris of the surface. At many places there are fragments of dull-gray rocks that look like sandstone, but these on being broken are yellow on the fresh surfaces. These are fragments of the phosphate rock. Fragments of manganese ore, which are easily recognized and always conspicuous when present, are good indications of the phosphate horizon, as the two are closely associated. Of course it must be remembered that loose material works its way downhill, so that only the upper limit of the material here described marks the position of the phosphate beds.

SUMMARY AND CONCLUSION.

While it is known that there is a phosphatic horizon of wide extent in northern Arkansas, the deposits have been developed at only one place, viz, on Lafferty Creek, in the western part of Independence County.

The geological formations of the vicinity of the developed deposits from below upward are: The Izard limestone, the Polk Bayou limestone, the Cason shale, the St. Clair limestone, the St. Joe marble, and the Boone chert. The developed deposits occur between the Polk Bayou limestone and the St. Clair marble, consequently at the horizon of the Cason shale, which is thought to be of Ordovician age.

The phosphate rock is of sedimentary origin, and where developed is light-gray, homogeneous, and conglomeratic, the pebbles being the size of peas and smaller.

The beds probably were laid down near shore as the sea advanced landward. Their phosphatic nature is thought to be due mainly to the fragments of organic matter that constitute so large a portion of their mass, though it may be due in part to the droppings of marine animals.

PHOSPHORUS ORE AT MOUNT HOLLY SPRINGS, PA.

By George W. Stose.

INTRODUCTION.

Phosphorus was formerly made solely from bones and organic substances, and it was not until the last decade, when the electric furnace was perfected, that natural phosphates were used to any extent in its manufacture. The extraction of phosphorus from mineral deposits brings the industry within the scope of the Geological Survey's investigations. The mineral from which phosphorus was first obtained was phosphorite, or rock phosphate, an impure fluophosphate of calcium, from which soluble phosphate fertilizer is generally made. Apatite, a fluophosphate or chlorophosphate of calcium, has been used in Europe and Canada to a small extent, but wavellite, or aluminum phosphate, so far as known, has not been heretofore used commercially in the manufacture of phosphorus, as the mineral does not generally occur in minable quantity.

DISCOVERY AND DEVELOPMENT.

At the foot of the northern slope of South Mountain, in the vicinity of Mount Holly Springs, Pa., 20 miles southwest of Harrisburg, a deposit of wavellite occurs in white clay associated with manganese and iron ores. For many years iron mining was a prosperous industry along the foot of the mountain in this region, but owing to competition from the great deposits of the West and South it has ceased to be profitable and the mines have long been idle. The iron is a secondary product, having been leached from the iron-bearing shales and limestones and deposited in the residual sand, gravels, and clays lying on the limestones in the valley. Associated with the iron, in general underlying it or on the side toward the mountain, is a body of clay, in places highly colored and plastic, elsewhere pure white or cream colored, siliceous, and less plastic. The extensive use of pure white clay as a filler for wall paper and for other commercial purposes

has created an increasing demand for the clay of this region, and it is extensively mined in the vicinity of Mount Holly Springs and prospected for everywhere along the mountain front. In one of these prospect pits, on the property of T. J. Spangler in the vicinity of Moores Mill, 4 miles west of Mount Holly Springs, peculiar round white nodules, chiefly in aggregates and botryoidal masses, were found in the white clay. The less weathered of these nodules when broken open show a beautiful radiate silky fibrous structure. The mineral proved to be a pure form of wavellite, or aluminum phosphate, a mineral that is rather uncommon in so pure a form and is not known to occur elsewhere in sufficient quantity to be mined. The American Phosphorus Company was organized by Philadelphia capitalists to develop the deposit, and a mill for the extraction of the phosphorus from the ore was built near the mine. T. J. Spangler, superintendent of the mine and owner of the land, is paid a royalty on the ore extracted. The mine was opened in 1900, the first years being devoted to prospecting and experimenting with the reduction of the ore. During 1905 the mine was in active operation and 400 tons of ore were reported to have been extracted and reduced in the company's furnaces.

The mine is operated by open cut. The phosphate is scattered through the white clay and appears to lie between a manganese deposit in reddish clay and the mountain. The open cut after reaching a depth of about 30 feet was stopped because of water. A shaft near by was said to have passed through clay with phosphate ore from a depth of 12 to 52 feet, at which point 16 feet of manganese ore was encountered. When examined in August, 1906, both the shaft and the open cut were filled with water and the workmen were stripping for an enlargement of the pit. A tunnel is to be dug from a ravine below to drain it, so that mining can be continued to greater depth. The deposit is apparently limited in width to 40 or 50 feet, with a depth ranging from a few feet on the valley side, to 50 feet on the mountain side, as indicated by the shaft, and is of undetermined length along the mountain.

The only other deposit of phosphorus ore discovered in this vicinity is on the other side of the ridge in the small valley east of Upper Mill, 1 mile south of Mount Holly Springs. In the clay prospects of J. L. Musser small bean-shaped fragments and nodules of the phosphate are associated with manganese ore, but its quantity and extent had not been determined. Wavellite was also observed by T. C. Hopkins [a] in the white clay deposits of North Valley Hill, on the north side of Chester Valley.

[a] Ann. Rept. Pennsylvania State College 1889-1900, appendix 3, p. 13.

GEOLOGY.

Cumberland Valley is a broad rolling plain 8 miles wide in the vicinity of Mount Holly Springs, whence it extends eastward to Susquehanna River and southwestward to Potomac River. It is limited abruptly on the southeast by South Mountain, a tract of parallel ridges which, near Mount Holly Springs, have an east-west trend.

The valley is composed largely of closely folded limestone of Cambrian and Ordovician age, younger Ordovician shales (Utica and Eden) overlying the limestone along the northwestern side of the valley. The front ridges of the mountain are made up of Cambrian quartzite and conglomerate with slate and soft sandstone valleys between. The southeastern ridges are of older volcanic rocks, both rhyolitic and basic.

In the vicinity of Mount Holly Springs the general structure is that of an anticlinorium with the southern limb covered by Triassic sediment. The lavas of pre-Cambrian age exposed at the axis are here chiefly rhyolitic and have a marked cleavage or schistosity dipping about 35° S., which obliterates largely the original banding. The basal Cambrian sediments consist of a coarse quartz conglomerate, massive quartzites, and thin slates. These are closely folded and overturned, dipping steeply to the south, although cleavage to the south is so highly developed that the stratification is difficult to determine. In the longitudinal valley of Mountain Creek a narrow belt of overlying limestone is infolded.

Walcott found fragments of *Olenellus* and *Hyolithes communis* in the upper scolithus-bearing sandstone just above Mount Holly Springs. This scolithus bed, which forms the north face of Mount Holly Ridge, resembles in every respect the Antietam sandstone, the uppermost sandstone of the mountain-making series of South Mountain in the vicinity of Chambersburg, and the finding of Georgian (Lower Cambrian) fossils in these beds further confirms this view, because fossils have not been found below this horizon in South Mountain. The limestone near the mountain is covered by wash. The nearest outcrops dip steeply to the south, being probably overturned, but fossils have not been found in them near Mount Holly Springs, so that the exact relations of the limestone to the sandstone of the mountain have not been determined. Walcott concluded[a] that a great fault exists along the west face of the mountain, agreeing in this respect with the earlier views of Lesley and Frazer, as published in the reports of the Second Geological Survey of Pennsylvania.

From recent detailed studies in South Mountain from the Maryland State line northward to the latitude of Chambersburg the writer has proved[b] the absence of a fault of any magnitude along that part of the

[a] Walcott, C. D., Cambrian rocks of Pennsylvania: Bull. U. S. Geol. Survey No. 134, 1896, pp. 24–27.
[b] Jour. Geol., vol. 14, 1906, pp. 201–220.

mountain front. Since the uppermost fossiliferous sandstone of the Cambrian (Antietam) forms the front of the mountain at Mount Holly Springs and there are no data concerning the age or attitude of the limestone immediately adjacent, it is assumed that the relations there are the same as those observed farther south; that is to say, that the sequence is normal or unbroken by a fault of appreciable magnitude.

ORIGIN.

The wavellite and the manganese and iron ores are secondary deposits in the surface gravels, sands, and clays which cover the rock outcrops at the foot of the mountain. These surface deposits are in part residual, in part transported. White sands, next to the mountain, are followed by beds of pure white siliceous clays, and these by colored plastic clays. The sand is derived from sandstones which have been leached of their calcareous cement, and in the quarries the loose sand merges into the unaltered rock. The white clay is a decomposed hydromica slate, transition into which has been described in the reports of the Second Geological Survey of Pennsylvania and by Hopkins.[a] Similar relations were observed in the clay mines by the writer,[b] but the exposures are not so clear and definite as they were when the iron mines were in active operation. The colored plastic clay is apparently derived from impure limestone. Generally these beds are steeply inclined or vertical, like the undecomposed rocks, but in places they have moved down the slope, lie flat, and have become covered over by and mixed with the quartzite débris from the mountain above.

In this heterogeneous mass the mineral deposits occur. Throughout the South Mountain district the iron ore that is associated with the basal part of the limestone is at the horizon of the hydromica slate at the contact with the sandstone, and is usually found in the highly colored clay, the limestone residuum, overlying the white clay derived from the hydromica slate. In many places the ore dips steeply into the hill parallel to the bedding and appears to be interbedded with the rocks.

It seems reasonable to conclude, therefore, that the original deposition of iron was in some way a feature of the change of sedimentation from shore detritus to calcareous silt, probably not as a massive bed of ore but as ferruginous sediments. The solution of the limestone and the decomposition of the other rocks has left the iron and clay residuum, and the iron has been further concentrated in the clay by solution and redeposition.

The wavellite undoubtedly had a similar history, for it is a common constituent of the iron and manganese ores. Analyses show its presence to a greater or less extent in all the iron ores of the region.

[a] Op. cit., pp. 11-13.

[b] See pp. 323-324 of this bulletin.

The phosphorus in some ores amounts to 0.5 per cent; in others it reaches 1.5 per cent. At Mount Holly Springs the wavellite occurs chiefly in nodular form, with radiate structure, inclosed in the white clay, but it is also found coating pieces of quartzite and manganese ore. The phosphorus was probably associated with the iron in its original occurrence and in the process of redeposition it combined with the alumina, but it is possible that it may have been in part derived from the phosphatic animal remains in the sediments. It is known that trilobites and other fossils with phosphatic skeletons once existed in these beds in considerable abundance. They are still found in the limestones, and their casts are occasionally observed in the sandstones, but the phosphatic material has all been removed from the porous beds by solution, and may have been deposited in the white clay adjacent to the iron and manganese.

MANUFACTURE OF PHOSPHORUS.

The old method of making phosphorus, which has been in use since the beginning of the nineteenth century, is as follows: Bones are roasted and crushed, and the powdered bone ash (calcium phosphate) is treated with sufficient sulphuric acid to convert all or part of the calcium into calcium sulphate and the phosphorus into calcium metaphosphate, or even into phosphoric acid. This is partially evaporated, mixed with powdered charcoal, and reduced in a furnace in a clay retort. Phosphorus vapor and carbon monoxide distill off, and the phosphorus is condensed under water in a yellow, waxy form. Theoretically the reaction would be as follows:

$$2Ca_3(PO_4)_2 + 6H_2SO_4 + 12C = 6CaSO_4 + 12CO + 2H_2 + P_4 + 4H_2O.$$

It is found in practice, however, that the following is more nearly what takes place:

$$3Ca_3(PO_4)_2 + 6H_2SO_4 + 10C = 6CaSO_4 + Ca_3(PO_4)_2 + 10CO + 6H_2O + P_4.$$

In this process much loss results from the destruction of the retorts by the acid and intense heat, and only about one-half of the phosphorus in the charge is recovered. There is also danger of igniting the phosphorus when removing it, and the greatest care is required to prevent the vapor from condensing in the tubes and clogging them. Many improvements and modifications of this process have been patented in recent years. Wöhler early suggested that calcium phosphate, either burnt bones or rock phosphate, be heated with sand and carbon without the sulphuric-acid treatment, and the Wing patent (1891) followed the same general method.

In the Wing process the charge of bone ash or pulverized rock phosphate and silica is moistened and made into balls, and is placed in the cupola in layers, alternating with coke or coal, which furnish incandescent carbon to reduce the phosphoric-acid fumes. The silica releases the phosphoric acid from the phosphate in the form of the anhydride P_2O_5, which is reduced by the incandescent carbon and a reducing flame to phosphorus. The fumes pass off to depositing chambers, kept at a temperature of 500° F., where most of the phosphorus is deposited in the red form and the remainder is caught in a water chamber as yellow phosphorus. The process is made continuous by feeding the charge from the top, dumping the residuum from the grate below, and using two depositing chambers alternately.

With only the ordinary furnace at command this method was found impracticable on account of the high degree of heat required to smelt so refractory a charge. Electricity as a powerful heating agent had been known for some time and was expected to furnish the solution of the problem, but only recently has the invention of the electric furnace made it commercially feasible. It has now been generally introduced throughout Europe and America in the production of phosphorus on a profitable basis.

The Readman patent (1889) is the process which has come into commercial use in most countries. Bone ash or crude phosphoric acid is mixed with powdered coal or charcoal, or, if mineral calcium phosphate is used, it is roasted, crushed, and mixed with charcoal and silica or some basic salt. The mixture is reduced in a continuously operated electric furnace in a reducing atmosphere, by passing the current from carbon electrodes through the mass, which acts as a resistant conductor and is heated to incandescence. The silica combines with the calcium to form calcium-silicate slag. The phosphorus and carbon monoxide distill off as before. Distillation begins at 1,150° C. and requires 1,400° to 1,500° C. to complete the process. The chemical reaction is—

$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C = 6CaSiO_3 + 10CO + P_4.$$

In Harding's patent (1898) pulverized rock phosphate is boiled with sulphuric acid, and the phosphoric acid, free from lime, is filtered out and boiled down to a sirup. This is mixed with granulated carbon heated in a reverberatory furnace, and then smelted in an electric furnace by electric arcs between the electrodes and the mass. A hydrogen atmosphere is obtained by spraying gasoline into the furnace.

In the Gibbs furnace, which was devised especially for the manufacture of phosphorus, instead of the electricity discharging through the mass, it passes through a continuous highly resistant medium, such

as a carbon rod, placed above the charge. The rod becomes incandescent, and the roof, which is arched over the grate, reflects the heat as in a reverberatory furnace.

The Readman process was modified by the Irvine patent in 1901. The charge is the same as in the earlier method, although either aluminum or calcium phosphate can be used with the silica or basic salt flux. The two carbon electrodes are suspended vertically from above and are connected below at the start by coal, through which the current passes. After the charge is melted the slag forms on top, and thereafter the current passes through it as the conductor between the electrodes. Fusion is continuous, and the excess of slag is tapped off gradually so as not to expose the ends of the electrodes.

A process patented in 1903 by Duncan takes 77 parts of powdered phosphate, either organic or mineral, and 23 parts of powdered carbon, mixed with tar as a binder. This is dried, and after a preliminary heating, as a matter of economy, in a hydrogen flame, a by-product in the manufacture, it is put into an electric furnace and calcium phosphide is continuously produced. This is put into a chamber submerged in hydrogen, and after adding water it forms phosphorus hydrides. On heating, the hydrides are reduced to phosphorus in pure state, either red or yellow, depending on the degree of heat at which it is allowed to deposit.

In 1902 Parker patented a process in England for the reduction of aluminum phosphate, which is treated with sulphuric acid and then with an alum-forming sulphate, all the alumina being removed by the crystallization of the alum previous to the electric treatment. The residual liquor is mixed with coal and other carbonaceous material and reduced in an electric furnace.

The American Phosphorus Company, through G. C. Landis, its chemist, secured a patent in January, 1907, on certain improvements in its furnace that were designed to prevent the escape of fumes, vapors, and gases, or their absorption by the furnace lining. This is accomplished by an outer lining of nonabsorbent brick and by a sealing device for all openings into the furnace, whereby the projecting flanges of the joints are inclosed in a moat of water. The furnace has an inner lining of carbon bricks that acts as one electrode, and one or more vertical carbon rods are used for the other electrode, which may be adjusted either to furnish a continuous current through the charge or to produce with it an electric arc.

The phosphorus obtained by most commercial processes is a crude form of the white or yellowish waxy variety, containing sand, carbon, clay, and other impurities. These are removed in various ways—by filtering while molten and submerged in water through powdered charcoal or through canvas; by forcing the molten mass through

porous pottery by means of steam; or by redistillation in iron retorts. The best method of purification, however, is to treat the crude phosphorus, when molten, with a mixture of potassium dichromate and sulphuric acid, or with sodium hypobromite, some of the impurities being dissolved and others rising to the surface as scum.

Because ordinary white phosphorus is very poisonous and injurious to handle, other forms of the element have been sought. Red amorphous phosphorus, which is not poisonous, is readily prepared by heating the ordinary variety to 250° C. in a closed vessel under pressure or excluded from air and water. It has not the same qualities, however, as the white crystalline variety. A red crystalline form, recently discovered in Germany, is made by heating to boiling a 10 per cent solution of white phosphorus in phosphorus tribromide. This form is not only nonpoisonous but is an efficient substitute for white phosphorus in making matches.

PRODUCTION.

The industry in this country is so young that statistics are difficult to obtain; in fact, general information on the subject is lacking. The world's production of phosphorus has been variously estimated to be from 1,000 to 3,000 tons a year, and until very recently this was almost entirely a foreign industry. The greater part of the world's supply is made in the Albright & Wilson factory, Wednesfield (Oldbury), England, where the Readman process originated. This plant is said to produce 500 tons a year. Other large factories are located at Lyons, France, and at Griesheim and Frankfort, Germany. There is also a plant in Sweden and numerous smaller ones in Russia, six of which, located near Perm, had an output of about 140 tons in 1890.

In the United States the first phosphorus works were built about forty years ago in Philadelphia by Moro Phillips, and this factory has continued in operation until very recently. J. J. Allen's Sons' plant was established in Philadelphia in 1891, and they supplied the Diamond Match Company, the largest match manufacturer in the United States, in competition with imported phosphorus. In 1897 the English firm of Albright & Wilson, under the firm name of the Oldbury Electro-Chemical Company, built at Niagara Falls a 300-horsepower factory of the Readman type, which has since supplied the Diamond Match Company and furnished the major portion of the domestic product. This company has recently made a further improvement in its plant by introducing the Irvine patent furnace, and it is reported that by this method 80 to 90 per cent of the phosphorus is extracted from the raw material, a high-grade phosphate rock. This is similar to the results obtained in the English works,

where 86 per cent is recovered. The company has six furnaces of 50 horsepower each, with a daily capacity of 170 pounds of phosphorus, a total of 1,020 pounds a day. The production varies according to the demand.

The General Chemical Company, a small domestic manufacturer and the successor of Mr. Phillips in Philadelphia, recently acquired the Duncan patent. Another company was formerly established at Long Island City, N. Y., where it operated furnaces by electricity from the city supply.

At the census of 1900 three establishments were reported in operation, but at the 1904–5 census only the Oldbury Electro-Chemical Company, of Niagara Falls, reported.

The American Phosphorus Company built its first mill at Moores Mill, near Mount Holly Springs, Pa., in 1902, and the old method of heating by gas was employed. This mill burned down and another was built and put into operation by 1905. Electric furnaces were installed in the new plant and operated during 1905, but the production of electricity by steam was too expensive, and in 1906 the mill was moved to Yorkhaven, Pa., where electricity generated by water power could be had. The process in use by this company is that of G. C. Landis, its chemist, and is kept a secret, as it is claimed that it is a marked improvement on previous methods. As far as could be learned for publication without detriment to the company's interest, the wavellite (aluminum phosphate) and phosphorite (calcium phosphate), which at present is obtained from South Carolina, are roasted, mixed with silica and charcoal, and reduced in a patented electric furnace. The slag is removed every three or four hours, and the phosphorus fumes are condensed under water in the crude yellow waxy form which requires refinement. Eighty-five to 90 per cent of the phosphorus in the ore is said to be extracted. The average production of this plant for the last three years is reported to be 500 pounds a day.

In addition to the domestic production, the United States imports annually 30,000 to 40,000 pounds of phosphorus, on which a duty of 18 cents a pound is paid. The price in the New York market ranges, according to quality, from 45 to 70 cents a pound.

USES.

Phosphorus is used chiefly for making matches, which were first manufactured on a commercial scale in 1833. Parlor matches were invented in 1848 and safety matches in 1855. The white phosphorus is used for ordinary matches and the red amorphous form for safety matches. On account of the injury to health in making and handling the ordinary phosphorus and the danger from fire in using

parlor matches, certain European countries have forbidden the manufacture and sale of the white variety, so that amorphous phosphorus and safety matches are coming into general use. The newly discovered crystalline red phosphorus is not only nonpoisonous, but is suitable for ordinary matches.

Phosphorus is sold in the market in round sticks molded through glass tubes and is usually stored under water. Its uses other than for matches are for fuse compositions, rat and insect poison, phosphoric acid, and other compounds used in medicine and the arts. It is also used in the precipitation of precious metals, electrotyping, and in phosphor-bronze.

SURVEY PUBLICATIONS ON PHOSPHATES AND OTHER MINERAL FERTILIZERS.

The following papers relative to phosphates, gypsum (land plaster), and other mineral materials used as fertilizers have been published by the United States Geological Survey or by members of its staff. Further references will be found under the head of "Gypsum" in the list on page 266 of this volume:

ADAMS, G. I., and others. Gypsum deposits in the United States. Bulletin No. 223. 127 pp. 1904.

DARTON, N. H. Notes on the geology of the Florida phosphates. In Am. Jour. Sci., 3d ser., vol. 41, pp. 102–105. 1891.

ECKEL, E. C. Recently discovered extension of Tennessee white-phosphate field. In Mineral Resources U. S. for 1900, pp. 812–813. 1901.

—— Utilization of iron and steel slags. In Bulletin No. 213, pp. 221–231. 1903.

—— The white phosphates of Decatur County, Tenn. In Bulletin No. 213, pp. 424–425. 1903.

ELDRIDGE, G. H. A preliminary sketch of the phosphates of Florida. In Trans. Am. Inst. Min. Eng., vol. 21, pp. 196–231. 1893.

HAYES, C. W. The Tennessee phosphates. In Sixteenth Ann. Rept., pt. 4, pp. 610–630. 1895.

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—— A brief reconnaissance of the Tennessee phosphate field. In Twentieth Ann. Rept., pt. 6, pp. 633–638. 1899.

—— The geological relations of the Tennessee brown phosphates. In Science, vol. 12, p. 1005. 1900.

—— Tennessee white phosphate. In Twenty-first Ann. Rept., pt. 3, pp. 473–485. 1901.

—— Origin and extent of the Tennessee white phosphates. In Bulletin No. 213, pp. 418–423. 1903.

IHLSENG, M. C. A phosphate prospect in Pennsylvania. In Seventeenth Ann. Rept., pt. 3, pp. 955–957. 1896.

MEMMINGER, C. G. Commercial development of the Tennessee phosphates. In Sixteenth Ann. Rept., pt. 4, pp. 631–635. 1895.

MOSES, O. A. The phosphate deposits of South Carolina. In Mineral Resources U. S. for 1882, pp. 504–521. 1883.

ORTON, E. Gypsum or land plaster in Ohio. In Mineral Resources U. S. for 1887, pp. 596–601. 1888.

PENROSE, R. A. F. Nature and origin of deposits of phosphate of lime. Bulletin No. 46. 143 pp. 1888.

STUBBS, W. C. Phosphates of Alabama. In Mineral Resources U. S. for 1883–84, pp. 794–803. 1885.

WILBER, F. A. Greensand marls in the United States. In Mineral Resources U. S. for 1882, pp. 522–526. 1883.

SULPHUR AND PYRITE.

THE COVE CREEK SULPHUR BEDS, UTAH.

By Willis T. Lee.

GENERAL STATEMENTS.

Location.—The sulphur deposits here described are owned by the Utah Sulphur Company, of Salt Lake City, and are located in central Utah, at Sulphurdale, a small mining camp about 20 miles north of Beaver, Utah, the nearest important town. The camp is not permanent and is deserted during the winter or whenever mining operations cease. The deposits are situated about 4 miles south of the site of old Cove Fort and are locally known as the Cove Creek sulphur beds. They are conveniently reached by team from Beaver, but the railroad connection or shipping point is Blackrock, a station on the San Pedro, Los Angeles and Salt Lake Railroad about 24 miles northwest of Sulphurdale.

Occurrence.—The sulphur extends from the surface downward to a considerable though unknown depth in beds of soft rhyolitic tuff and varies in amount in different parts of the beds. An area of several acres has been exploited, the sulphur having been mined more or less continuously for 30 years, but the lateral extent as well as the depth of the deposits is unknown.

Neighboring deposits.—There are several more or less widely separated deposits of sulphur in the vicinity of Sulphurdale, ranging in a general northeast-southwest direction. One deposit 3 miles north of the camp is said to have been worked to some extent, but the other prospects have not been developed, although they are said to show indications of considerable quantities of sulphur.

GEOLOGY.

Formations.—The Paleozoic sediments of the plateau region probably occur at a considerable depth beneath the surface at Sulphurdale. Their nearest exposures are at the north end of Mineral Mountains and in the Beaver River range to the west, where they dip eastward beneath the extrusive rocks which cover the surface.

The Tushar Mountains, near the north end of which the sulphur beds occur, are composed of eruptive rock consisting, so far as examined, of flows, breccias, and tuffs of rhyolite overlain in places by andesite. Much of the tuff is soft, fine-grained, and snowy white. The rhyolites presumably rest upon sedimentary rocks, as in neighboring regions, and are apparently several thousand feet thick. The sulphur occurs in the white tuff, which some of the miners call "gypsum."

In the vicinity of Sulphurdale basalt overlies the rhyolites and andesites in slightly eroded flow sheets and crater cones. Two conspicuous cones having well-defined craters occur near the sulphur beds, one about 10 miles to the southwest, the other 3 miles west of the camp. Still other cones and associated flows are situated farther north, forming a linear group lying essentially parallel to the neighboring mountain ranges. The fresh appearance of the lavas and the slight amount of erosion of the cones indicate recent formation, and lavas of similar character near Blackrock rest upon the Bonneville beds, from which fact it seems probable that the cones were formed during late Quaternary time.

Structure.—There are reasons for believing that the sulphur beds are located in or near a zone of intense faulting and volcanic activity and that the conflicting forces causing the disturbances have not yet reached a state of equilibrium. Evidence of this is found not only in the vicinity of Sulphurdale, but for long distances both north and south of this place.

Along the western border of the high plateaus of Utah, from St. George northeastward, several basins have been formed by faulting, accompanied or followed by the movement of large crust blocks. Rush Lake Valley and Parowan Valley are perhaps the most conspicuous of these basins. The strata of the plateau to the east lie essentially horizontal, while those to the west dip eastward beneath the valleys. In the Beaver basin this simple relation is complicated by the great masses of effusive rock which cover the sediments, but west of the basin, in the vicinity of Minersville, and again at the north end of Mineral Range, the Paleozoic sediments appear underneath the effusives, dipping eastward beneath the basin. From this it is inferred that Beaver Valley, like those farther south, is due to crustal movement and that the great fault zone which follows the western margin of the plateau through Rush Lake and Parowan valleys, and along which displacements of thousands of feet are known to have occurred, probably continues through Beaver Valley, and thence northeastward past Sulphurdale.

Several phenomena noted mark this zone as one of recent disturbance. The line of sulphur beds, from which hydrogen sulphide is still escaping in large quantities, and less exactly the line of the recent

volcanic cones, coincide with it or lie parallel to it. The region between St. George and Fillmore is known as a zone of frequent and severe earthquakes, several shocks of sufficient force to destroy buildings having occurred there within the memory of men still living in this vicinity.

SULPHUR.

CHARACTER OF ORE.

Some of the sulphur occurs in cylindrical masses or cores 10 or 15 feet in diameter, having a rude radial structure, as if they had been formed about a central vent that extended downward into the beds of tuff, but it occurs mainly as a dark-colored impregnation or cementing substance in the rhyolitic tuff. In certain places it appears as irregular veins of nearly pure yellow sulphur ramifying through the beds. These veins, some of which are several inches thick, are usually banded parallel to the walls and are evidently filled fissures. The sulphur is apparently deposited in some way from solution, since in several places acid water, an analysis of which is given below, was found issuing from small fissures partly filled with yellow sulphur. Here and there a small cavity is lined either with flowers of sulphur or with sulphur crystals.

The ore varies greatly in richness; at some places there is only a trace, at others there are masses of practically pure sulphur. Samples taken at the extremities of the workings have been analyzed by E. C. Sullivan, of the United States Geological Survey, and found to contain, respectively, 80 and 65 per cent of sulphur. The first sample was taken from a horizontal sheet 8 feet thick and the second from a vertical dikelike body 4 feet thick. There is a large quantity of equally rich ore and much that is not so rich. Material having as low as 15 per cent of sulphur, however, is considered paying ore.

The cost of production is doubtless much greater than it would be if the mining were done on a scale sufficiently large to warrant the installation of modern machinery. The stripping to a depth of 10 feet or more is done entirely by horses and scrapers, much of the material having been moved several times, and the ore is removed by manual labor, whereas both operations might easily be performed with steam shovels at greatly reduced cost.

At the smelter the ore is placed in iron retorts and the sulphur melted out by steam, which is forced into it under a pressure of about 60 pounds, representing a temperature of 144° C. The melted sulphur finds its way to the bottom of the retort and is drawn off into iron receptacles, in which it cools and hardens into cakes weighing about 200 pounds each. In this form it is stored until needed, when it is ground into flour and sacked for shipment. The rate of extraction is slow, but experience has shown that an attempt to hasten it by raising

the temperature of the steam results in diminishing the output and in some cases has almost wholly stopped the process. The steam pressure employed varies somewhat with the kind of ore. Cedar wood, which grows in abundance in this vicinity, is used as fuel.

The sulphur as it comes from the retort has been analyzed by Herman Harms, State chemist of Utah, who reports the composition as follows:

Analysis of sulphur from retort at Sulphurdale, Utah.

Sulphur	99.71
Nonvolatile residue (silica, iron oxide, etc.)	.23
Free sulphuric acid	Trace.
Sulphurous acid	0
Arsenic	0
Moisture at 100° C	.06
	100.00

ORIGIN.

Several facts noted seem to point clearly to the mode of origin of the sulphur. The geologic relations, previously stated, indicate that the deposits are on or very near a fault line and are closely associated with volcanic rocks. The presence of a recently extinct volcano to the west, the flows from which extend within about a mile of the sulphur beds, suggests that the sulphur may have resulted from the eruptions of this volcano. Gas is now escaping here in large volumes; in some places through vents suggesting those supposed to have given rise to the cylindrical cores of sulphur; in other places through thousands of small jets from the porous beds of tuff, giving rise to the general dissemination of the sulphur through the beds. Wherever water stands in the excavations the gas boils up through it at short intervals. No sulphur dioxide (SO_2) was noted, but the disagreeable odor of hydrogen sulphide (H_2S) was strongly perceptible. The occurrence of large quantities of hydrogen sulphide suggests that this gas is the source of the sulphur. When it comes into contact with oxygen in the porous tuff near the surface it is probably oxidized, losing its hydrogen and dropping the sulphur as expressed by the simple formula:

$$H_2S + O = H_2O + S.$$

The sulphur being a solid remains where it is set free in the porous tuff. If this explanation is correct, continued oxidation would form a certain amount of sulphur trioxide ($S + 3O = SO_3$), which in combination with water forms sulphuric acid ($H_2O + SO_3 = H_2SO_4$). It is a matter of interest in this connection to observe that the water issuing from the beds is strongly charged with acid, as shown by the following analysis made by W. M. Barr, of the United States Geological Survey:

Analysis of water from Cove Creek sulphur beds.

[Parts per million.]

Dissolved solids at 180°	8,816
Dissolved solids at 130°	10,810
Suspended matter	52
Silica (SiO_2)	124
Ferrous oxide (FeO)	560
Ferric oxide (Fe_2O_3)	802
Aluminum (Al)	0
Calcium (Ca)	158
Magnesium (Mg)	232
Sodium (Na) } Potassium (K) }	114
Carbonate radicle (CO_3)	0
Bicarbonate radicle (HCO_3)	0
Sulphate radicle (SO_4)	7,602
Free sulphuric acid (H_2SO_4)	4,523
Chlorine (Cl)	79
Nitrate radicle (NO_3)	1.7
Free sulphur (S)	3.6

NOTE.—Constant loss of dissolved solids occurs when heated above 130°. Heated at 180° not constant. Sample had free hydrogen sulphide (H_2S) when collected, with possible presence of sulphur dioxide (SO_2).

The veins filled with yellow sulphur and the cavities lined with crystals or flowers or sulphur might be interpreted as indicating that the sulphur came up in melted or vaporized condition. The quantity occurring in this way, however, is very small compared with that contained in the tuff, and may be due to some secondary action.

CONCLUSION.

The facts and inferences regarding the occurrence and origin of the Cove Creek sulphur deposits may be summarized as follows:

There are valuable deposits of sulphur not only at Sulphurdale, where it is being extracted, but at several other localities in the same neighborhood. The Cove Creek sulphur beds have supplied the local market for about thirty years, their average annual output being estimated at 1,000 tons. The sulphur is probably the result of volcanic action, as is shown by its presence in a volcanic region where recent eruptions have occurred. It is presumably derived from hydrogen sulphide, which is still escaping in large quantities, and its concentration in the beds of rhyolitic tuff is probably due to the general dissemination of the gas through the porous material near the surface, where it comes in contact with oxygen which unites with the hydrogen to form water, leaving the sulphur as a cementing substance in the loose material. The process of formation and concentration is apparently active at the present time.

SURVEY PUBLICATIONS ON SULPHUR AND PYRITE.

The list below includes the important publications of the United States Geological Survey on sulphur and pyrite:

ADAMS, G. I. The Rabbit Hole sulphur mines, near Humboldt House, Nev. In Bulletin No. 225, pp. 497–500. 1904.

DAVIS, H. J. Pyrites. In Mineral Resources U. S. for 1885, pp. 501–517. 1886.

ECKEL, E. C. Gold and pyrite deposits of the Dahlonega district, Georgia. In Bulletin No. 213, pp. 57–63. 1903.

——— Pyrite deposits of the eastern Adirondacks, N. Y. In Bulletin No. 260, pp. 587–588. 1905.

MARTIN, W. Pyrites. In Mineral Resources U. S. for 1883–84, pp. 877–905. 1886.

RICHARDSON, G. B. Native sulphur in El Paso County, Tex. In Bulletin No. 260, pp. 589–592. 1905.

ROTHWELL, R. P. Pyrites. In Mineral Resources U. S. for 1886, pp. 650–675. 1887.

SPURR, J. E. Alum deposit near Silver Peak, Esmeralda County, Nev. In Bulletin No. 225, pp. 501–502. 1904.

INDEX.

I.

J.

K.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 315.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the ninety-fifth in Series A, the complete list of which follows (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES A, ECONOMIC GEOLOGY.

B 21. Lignites of Great Sioux Reservation: Report on region between Grand and Moreau rivers, Dakota, by Bailey Willis. 1885. 16 pp., 5 pls. (Out of stock.)

B 46. Nature and origin of deposits of phosphate of lime, by R. A. F. Penrose, jr., with introduction by N. S. Shaler. 1888. 143 pp. (Out of stock.)

B 65. Stratigraphy of the bituminous coal field of Pennsylvania, Ohio, and West Virginia, by I. C. White. 1891. 212 pp., 11 pls. (Out of stock.)

B 111. Geology of Big Stone Gap coal field of Virginia and Kentucky, by M. R. Campbell. 1893. 106 pp., 6 pls. (Out of stock.)

B 132. The disseminated lead ores of southeastern Missouri, by Arthur Winslow. 1896. 31 pp. (Out of stock.)

B 138. Artesian-well prospects in Atlantic Coastal Plain region, by N. H. Darton. 1896. 228 pp., 19 pls.

B 139. Geology of Castle Mountain mining district, Montana, by W. H. Weed and L. V. Pirsson. 1896. 164 pp., 17 pls.

B 143. Bibliography of clays and the ceramic arts, by J. C. Branner. 1896. 114 pp.

B 164. Reconnaissance on the Rio Grande coal fields of Texas, by T. W. Vaughan, including a report on igneous rocks from the San Carlos coal field, by E. C. E. Lord. 1900. 100 pp., 11 pls. (Out of stock.)

B 178. El Paso tin deposits, by W. H. Weed. 1901. 15 pp., 1 pl.

B 180. Occurrence and distribution of corundum in United States, by J. H. Pratt. 1901. 98 pp., 14 pls. (Out of stock; see No. 269.)

B 182. A report on the economic geology of the Silverton quadrangle, Colorado, by F. L. Ransome. 1901. 266 pp., 16 pls. (Out of stock.)

B 184. Oil and gas fields of the western interior and northern Texas Coal Measures and of the Upper Cretaceous and Tertiary of the western Gulf coast, by G. I. Adams. 1901. 64 pp., 10 pls. (Out of stock.)

B 193. The geological relations and distribution of platinum and associated metals, by J. F. Kemp. 1902. 95 pp., 6 pls.

B 198. The Berea grit oil sand in the Cadiz quadrangle, Ohio, by W. T. Griswold. 1902. 43 pp., 1 pl. (Out of stock.)

PP 1. Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska, by A. H. Brooks. 1902. 120 pp., 2 pls.

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